TECHNOLOGY OF LIGNITIC COALS

In Two Parts—Part 2: Combustion—Power Generation; Carbonization; Gasification; Hydrogenation; Other Chemical Processing

By Bureau of Mines staff, Grand Forks, N. Dak., and Washington, D. C.

* * * * * * * * * * **Information Circular 7692**

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J. J. Forbes, Director

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FOREWORD

Since its creation by the Congress in 1910, the Bureau of Mines has fostered prudent exploitation of our mineral and mineral-fuel resources. Even though the United States has abundant reserves of solid fuels, sufficient to last many centuries with wise use of present reserves, it is recognized that development of our lower rank fuels in the vast untapped reserves of the North Central States will greatly enhance our mineral wealth.

Lignite as a source of fuel and chemical materials has long been regarded as an important asset to the Nation's economy. As the reserves of the higher rank coals of the Appalachian region are eventually depleted, large quantities of lower rank coals will be required to maintain our position of leadership in the industrial world. In view of this, the Bureau of Mines has been conducting investigations to develop more efficient methods of utilizing our vast reserves of lignitic coals. One notable accomplishment in this direction is the construction of a large Texas power plant, in which it is planned to employ lignite char as fuel for power generation.

This char manufacturing process with its accompanying valuable tars is the outgrowth of a process developed by the Bureau of Mines at its Denver Station. In 1951, construction of the Bureau's Charles R. Robertson Lignite Laboratory was completed at Grand Forks, N. Dak. It is anticipated that the major lignite projects of the Bureau will be conducted at this laboratory in cooperation with industry and the various Government agencies.

This report is composed of two parts; part 1 covers the technology of European lignitic coal, statistics on production and costs of North Dakota lignitic coals, their occurrence and properties, mining, preparation, storage, and transportation; part 2 covers the utilization of lignite. Owing to the broad field discussed, it was necessary that contributions of a number of Bureau authors be assembled and integrated to facilitate the final product. A major portion of the work emanated from the Bureau's lignite laboratory at Grand Forks, N. Dak., under the guidance and authorship of Robert McMurtrie, chief of the Lignite Branch of that station, and under the general supervision of J. Daniel Lankford, chief, Fuels Technology Division, Region V, Minneapolis, Minn. Significant contributions were made by Walter H. Oppelt, Robert C. Ellman, Edward F. Golob, Gordon H. Gronhovd, Jerome J. Hoeppner, Jr., Theodore W. Kamps, Jr., Wayne R. Kube, and Alfred Traverse.

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TECHNOLOGY OF LIGNITIC COALS

Part 2 of Two Parts

by

Bureau of Mines staff, Grand Forks, N. Dak., and Washington, D. C.

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1. COMBUSTION - POWER GENERATION

The lignite deposits of the United States represent a huge potential source of fuel for power generation. It has been estimated that lignite constitutes about 24 percent of the remaining National reserves of solid fuel on a tonnage basis and about 15 percent of the reserves on a B.t.u. basis. (See sec. 3, part 1.) The major portion of these reserves is in North Dakota.

Lignite has been used locally for domestic heating since the first settlers burned it at forts and fur-trading posts as early as 1855. Some of the first studies of the use of lignite in steam boilers were conducted by the Federal Bureau of Mines from 1910 to 1920 (15, 19).1/ However, the commercial utilization of lignite as fuel for producing power developed slowly. Not until about 1925 was any really successful lignite industrial fuel-burning equipment developed. Since then the commercial use of lignite as a fuel for producing power has been increasing steadily.

Because of its high moisture content, low heating value, and lack of preferential transportation rates, lignite has a more restricted area of competition than is generally true of higher rank coals. The approximate extent of the lignite-consuming area is shown in figure 36 (see sec. 6, part 1) and analyses and characteristics of North Dakota lignites are discussed in sec. 3, part 1.

When used with properly designed fuel-burning equipment, lignite has proved to be a satisfactory fuel for power generation. With the equipment now being used, the disadvantage of high moisture content in lignite is largely overcome, as regards firing and heat-release conditions in the furnace, although, obviously, greater amounts of fuel and ash must be handled per unit quantity of power generated than with higher rank coals.

It is interesting to note the important role that coal is playing in the rapidly expanding electric utilities industry in the Nation. Utility power-generating capacity is growing at the fastest rate in history. In 1950 approximately 50 percent (21) of the total energy output of electric utilities was generated with coal. Trends indicate a continued expansion of electric utilities with greatly increased consumption of coal in the near future. The utilization of North Dakota lignite in electric utilities plants has increased quite rapidly in the last few years also. For example, in 1944 the annual production of lignite in North Dakota was 2,516,000 tons, of which 54 percent (1) was used domestically and 46 percent was used industrially. By 1951 the output had expanded to 3,281,000 tons, with an increase in industrial use to 66 percent (14) and a decrease in domestic use to 34 percent. The increased use of fuel oil for domestic heating has caused the rapid reduction in the domestic coal market.

Methods of Firing

Lignite has been successfully burned in power boilers by each of the following methods: Underfeed stoker, traveling-grate stoker, spreader stoker, pulverized firing, and the cyclone burner. The underfeed stoker was never very popular for use with

1/ Underlined numbers in parentheses refer to citations in the bibliography at the end of this section.

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lignite, and it is now considered obsolete. The first real progress in the utilization of lignite for power plants was brought about by the successful development of forced-draft traveling-grate stokers. This method of firing lignite was used extensively for a number of years. However, it now has been largely replaced by the more versatile spreader stoker. Most of the power plants constructed in the last few years are fired with spreader stokers used in conjunction with a traveling grate. However, the boiler-size limitation inherent in this method of firing, which will be discussed elsewhere in this section, is such that for large installations the unit-pulverizer method has been chosen. The use of pulverized-lignite firing for large central power stations will, no doubt, be further expanded in the future. The recently developed cyclone burner has been found, in one plant test, to give satisfactory operation with lignite.

The various methods of firing lignite in power boilers are discussed in further detail below:

Underfeed Stokers

In an underfeed stoker coal is introduced through a retort beneath the fuel bed. The volatile gases are distilled off and burned as the coal moves up through the incandescent fuel bed. Air for combustion is introduced through tuyères that form the sides of the retort. The fuel bed for underfeed stokers is usually quite thick and requires considerable agitation to move the fuel. Since lignite is a free-burning coal, which does not hold together, and when underfed burns in a very thin layer, it tends to drift or avalanche as a result of the air pressure and bed agitation. For this reason underfeed stokers have not been used extensively with lignite. Other disadvantages common to this method of firing are high maintenance costs and lack of flexibility in operation. Although there have been some reasonably satisfactory installations with underfeed stokers (5, 18) fired with lignite, at present this type of unit is not being used in any power-generating station in the North Dakota lignite-burning region.

Chain- and Traveling-Grate Stokers

There is a distinction between chain-grate and traveling-grate stokers, based on the link attachment and drive mechanism; but operation of both is essentially the same, and for the purposes of this discussion they will not be considered separately. In either instance, cast-iron links are assembled to form an endless grate, which is driven around a supporting structure by suitable chains and sprockets. Its operation is similar to that of a conveyor belt. Fuel is fed by gravity from the hopper and forms a level, uniform bed on the moving grate surface. The fuel is ignited by the radiated heat from the ignition arch and by hot gases forced over the bed by the rear arch. Forced draft is supplied to compartments between the strands of the grate. Each compartment has a damper for zoning and controlling the air to the various sections of the grate. As the grate moves the coal toward the rear of the furnace, the combustion process is completed, and the ash is automatically discharged into the ash hopper.

Since the fuel bed is not agitated with this type of stoker it is well-adapted for use with free-burning coals, such as lignite. During the period from 1921 to 1948 a number of forced-draft, traveling-grate stokers were installed in lignite-burning power plants in the United States and Canada. The early units were designed for preheated air temperatures (18) of about 300° F. It has since been found desirable to increase air temperature to 400° F. or more to improve the speed and stability of ignition. By increasing the preheated-air temperatures, it has been possible to obtain combustion rates considerably higher than those for which the unit was originally designed. Various types of ignition arches were tried with traveling-grate stokers. The most successful design (5) has been a low, long, water-cooled rear arch. The rear-arch design is used to force hot combustion gases across the bed top to increase both ignition and burning

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rates. Overfire air jets have been successfully used to create turbulence and mix the furnace gases, improving combustion.

Proper size consist and distribution of the lignite feed on the grate are important factors in obtaining good operating results with this method of firing. If the fuel bed is not uniform, owing to improper sizing of the coal, blowholes may occur and air distribution will not be uniform over the fuel bed. The coal size used with this method of firing ranges from 1- to 1-1/2-inch maximum size, with the permissible percentage of fines depending upon the draft used.

The largest boilers in the North Dakota lignite-burning region using traveling-grate stokers are the units at the Kidder station of the Otter Tail Power Co. at Wahpeton, N. Dak. This plant has two boilers of 100,000-pound-steam-per-hour capacity fired by this method. These units have maximum efficiencies of about 80 percent. A number of smaller furnaces (2, 12) in this region successfully use this type of stoker, and it has been estimated that a unit as large as 200,000-pound-steam per hour could be successfully fired with a traveling-grate stoker burning lignite. Figure 1 (12) shows a typical lignite-fired traveling-grate installation. This unit was installed at the Devils Lake station of the Otter Tail Power Co. in 1947. Operating-performance data (12) for this boiler are shown in figure 2.

Because of the characteristic of traveling grates to respond slowly to load changes owing to the relatively large quantity of fuel on the grate at one time and because of difficulty in burning coal with a high percentage of fines efficiently, the trend is toward the use of other types of stokers in the new installations.

Spreader Stoker

With spreader stokers, coal is thrown into the furnace and uniformly distributed over the grate either mechanically, as with a rotor, or pneumatically. Dumping or traveling grates may be used. The latter has proved to be more desirable for large boilers (7) because it offers the following advantages: A cleaner boiler room, no fuel-bed agitation, no loss in rating during ash discharge, and a lower combustible content in the ash. The traveling grate normally moves toward the front of the boiler. Primary air is introduced below the grates, and overfire air is supplied above the fuel bed. Fine portions of the fuel are dried and burned in suspension when thrown into the highly heated furnace cavity. The larger particles, which also are partly dried in suspension, fall to the grate and are burned there. Other things being equal, the percentage of fuel burned in suspension is a function of the size distribution of the fuel fed to the unit. Because of high moisture content, lignite shatters easily when exposed to the furnace atmosphere. Consequently, the portion burned in suspension and the amount of fly ash produced are greater when lignite is burned than when higher rank coals are fired by this method.

In early installations boiler passes plugged owing to the long flame and large quantity of fly ash having a low fusion temperature. To correct this condition, furnace heights were increased, slag screens were added, and water-wall construction was used to reduce furnace outlet temperatures (13). As a result of the large percentage of fuel burned in suspension, the fuel bed is thin, and high-resistance grates are used with spreader stokers to control undergrate air distribution and flow. Preheated air temperatures as high as 400° F. are used with spreader stokers. Most installations utilize overfire air to prevent stratification of furnace gases, create turbulence in the furnace cavity, reduce fly ash carryover, and sometimes to control superheat.

Less superheater surface per pound of fuel burned is required when lignite is burned than with other coals because of the greater volume of gases resulting from evaporation of the moisture in the lignite.

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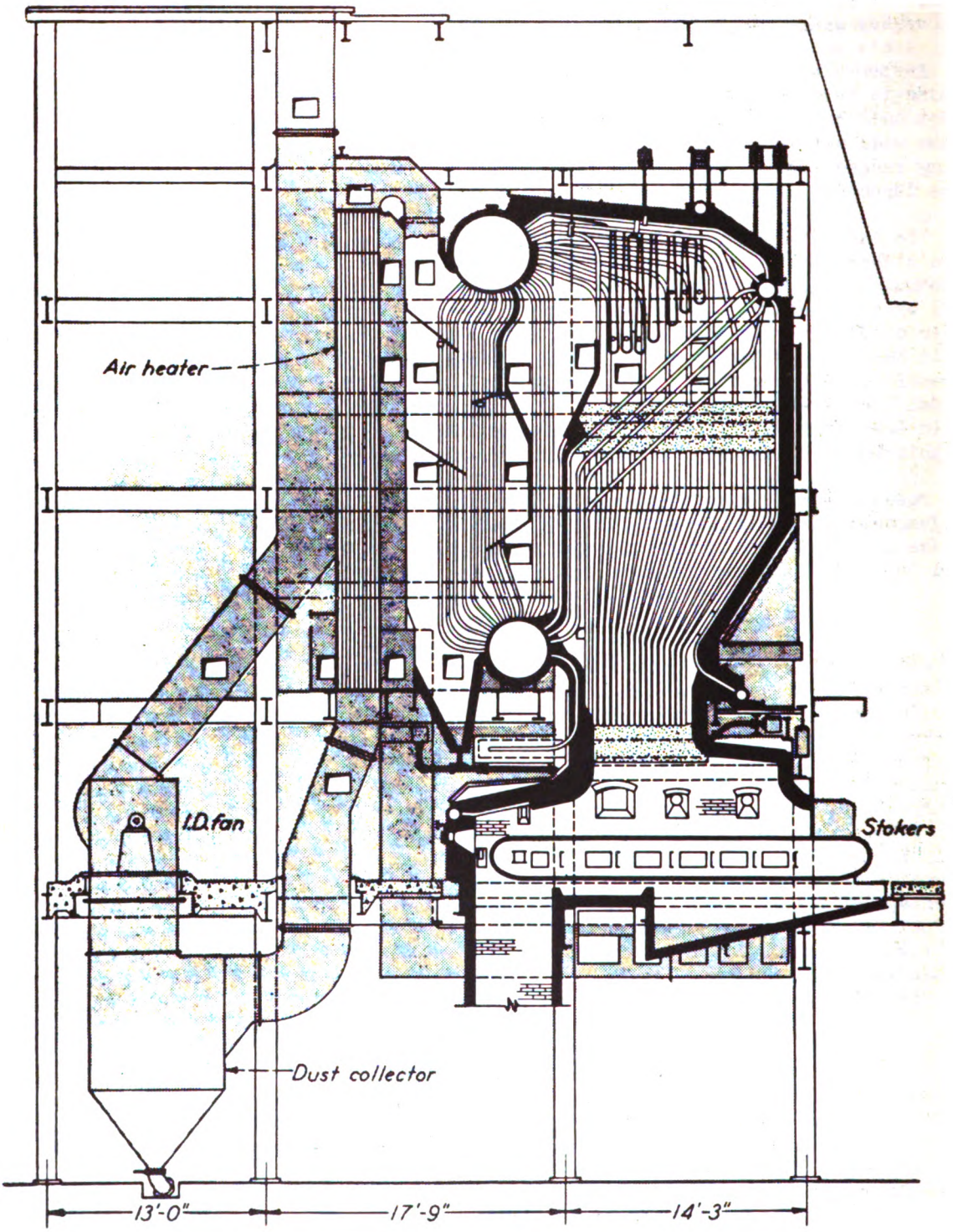

Figure 1. - Traveling-grate-fired steam generating unit of 75,000-pound-steam-per-hour capacity at Devils Lake station of the Otter Tail Power Co., Devils Lake, N. Dak. See reference (12) in section 1.

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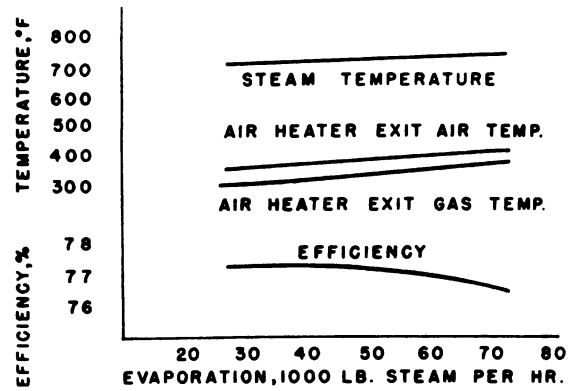
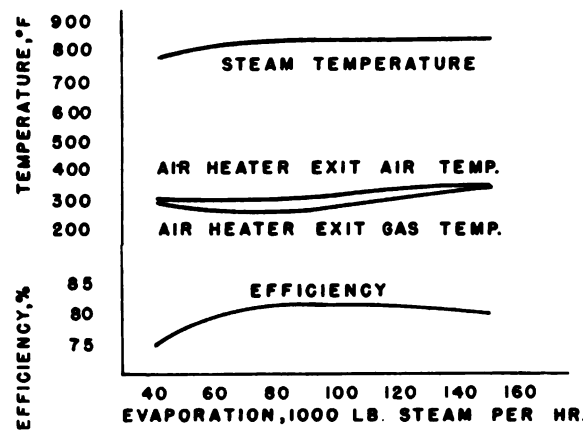
TRAVELING GRATE STOKER:
PERFORMANCE RECORD OF STEAM GENERATOR AT DEVILS LAKE STATION. SEE FIG. 39 FOR BOILER DESIGN.



SPREADER STOKER:
PERFORMANCE RECORD OF STEAM GENERATOR AT MINNKOTA STATION.



UNIT PULVERIZER:
PERFORMANCE RECORD OF STEAM GENERATOR AT CROOKSTON STATION. SEE FIG. 45 FOR BOILER DESIGN.

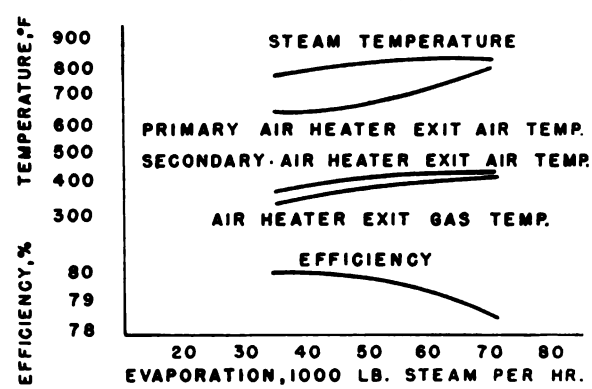


Figure 2. - Performance of three steam generators fired by traveling grate stoker, spreader stoker, and unit pulverizer.

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Dust collectors usually are installed with spreader stokers. Some plants reinject cinders, but the large quantity of fly ash and the low combustible content of the ash do not make this practice as desirable with lignite as with other coals. If ash is reinjected, it usually consists of that caught from the boiler pass and air heater, although sometimes dust from the dust collectors is reinjected also (13).

The commercial sizes of coal most commonly used are 2- by 0-inch or 1-1/2- by 0-inch screenings with a considerable percentage of fines (under 1/2 inch). One of the most important operating factors for the spreader stoker; and one to which the stoker is most sensitive, is the size distribution of the feed. Almost any kind of coal can be burned successfully with the spreader stoker, provided the sizing is correct. For this reason, the spreader stoker often is chosen for plants having more than one type of coal available. Some of the other advantages of spreader stokers are (4, 7) low investment cost, low power requirements, low maintenance costs, rapid response to load changes, rapid starting, and ability to respond quickly from a condition of live bank.

Boiler capacity with spreader firing is limited by the distance the coal can be thrown with proper distribution. In present practice this distance is 18 to 19 feet. As a result, the maximum economic boiler capacity is considered to be approximately 250,000 pounds of steam per hour (13).

The largest spreader-stoker installation burning North Dakota lignite is the Ortonville plant of the Otter Tail Power Co., which has a capacity of 160,000 pounds of steam per hour.

Some disadvantages of this method of firing are: The possibility of considerable fly-ash carryover, frequent renewal of the fuel bed necessitated when operating with dump grates, and rapid burning out of the fire if the coal feed stops, owing to the small amount of coal on the grates.

A good example of a large modern spreader-stoker installation for burning lignite is the newest boiler at the Minnkota station, Grand Forks, N. Dak. This unit was added to the station in 1950. It is rated at 135,000-pound-steam-per-hour continuous capacity and has a maximum 4-hour capacity rating of 150,000 pounds of steam per hour. Steam is generated at 615 p.s.i.g. and 825° F. The boiler is of the bent-tube type, with complete water-wall construction. It is fired by two spreader-type stokers with chain-grate ash removal. Each stoker has an active grate width of approximately 12 feet and 170 square feet of grate area exposed to the furnace. Six overthrow-type coal feeders driven from a common line shaft supply fuel to the boiler. The superheater is constructed in two sections and is of the center interbank vertical pendant type. A return-bend loop-header-type economizer received the gases from the boiler outlet. The tubular-type air pre-heater is constructed in two sections. The larger section receives gases from the economizer, and the smaller section is installed on the discharge side of the dust collector. The furnace is designed to reinject the cinders from the last pass hopper. Additional overfire air is supplied by a separate fan.

Performance tests were run on this furnace in May 1950. The principal operating data from this test are plotted in figure 2. Overall boiler efficiencies exceeding 80 percent were maintained from about 45 to 115 percent of the rated load. Preheater-air temperatures range from 300° to 350° F. Ash samples were collected from the last-pass hopper and dust-collector hopper during part of the test to determine the reduction in combustible content by cinder reinjection. Less than 1 percent difference in combustible content of the ash was found for the two samples. Figure 3 shows graphically how the combustible content in the dust-collector hopper refuse increased with boiler capacity, whereas that of the ash pit refuse decreased.

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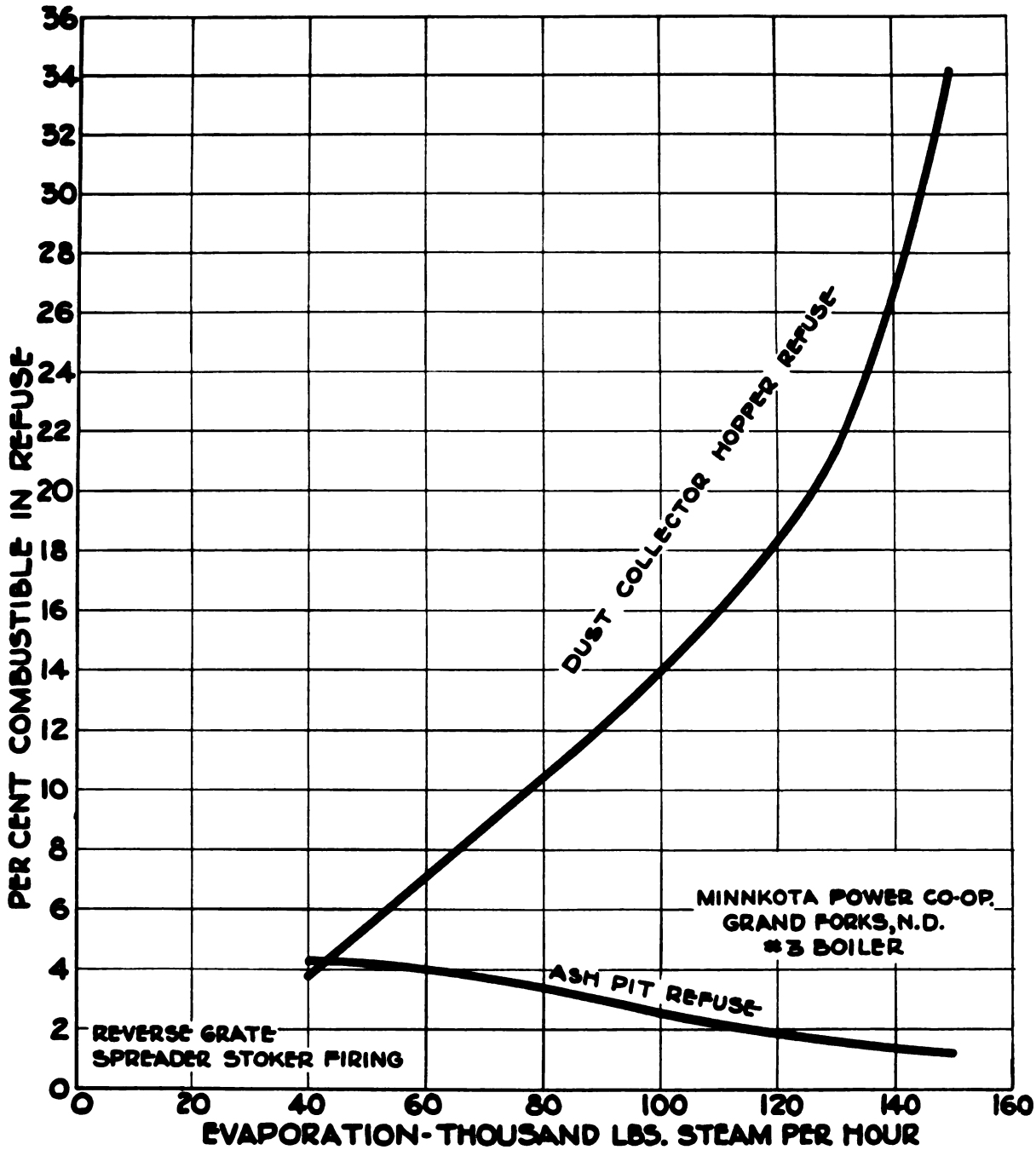

Figure 3. - Percentage combustible in the refuse as a function of boiler load during performance test on 135,000-pound-steam-per-hour boiler at the Minnkota station, Grand Forks, N. Dak. See reference (18) in section 1.

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Operating data, taken from the plant reports for 1952 for the entire Minnkota station on a monthly and yearly basis, are given in table 1. As would be expected, the average boiler efficiencies are lower than those shown in the charts for performance tests.

TABLE 1. - Summary of operating data, 1952, Minnkota station, Minnkota Power Cooperative, Inc., Grand forks, N. Dak.

(Data supplied by Minnkota Power Cooperative, Inc.)

Fuel costs.....cents per million B.t.u.	31
Boiler efficiency.....percent	77
Station heat rate.....B.t.u. per net kw.-hr.	15,582
Station consumption.....percent of gross power generated	6.17
Plant factor[1]/.....percent	70
Running plant capacity factor[2]/.....do.	85
Fuel cost.....mills per net kw.-hr.	4.61
Operating labor.....do.	0.63
Maintenance including material.....do.	0.23
Miscellaneous.....do.	0.11
Total production expense.....do.	5.58
Station heat rate, best month.....B.t.u. per net kw.-hr.	15,076
Boiler efficiency, best month.....percent	77.4
Station consumption, best month..... .....percent of gross power generated	5.05

1/ Plant factor = $\frac{\text{gross kw.-hr. generated per yr.}}{\text{(hr. per yr.) (Installed capacity in kw.)}}$

High plant factor is maintained at Minnkota station by using the diesel plant for peak loads. Diesel plant capacity is 15,000 kw.

2/ Running plant capacity factor = $\frac{\text{Gross kw.-hr. generated per yr.}}{\text{(Hr. operated per yr.) (installed capacity in kw.)}}$

In figure 4 ash-collection data are presented for one of the two 72,000-pound-steam-per-hour boilers at the Minnkota plant. The boiler design is shown in figure 5. These units are similar in design to the large boiler. Shown on the graph are typical percentages of total ash collected in the stoker ash hopper, in boiler and air-heater soot hoppers, in economizer soot hoppers, and dust collectors. The percentages of combustible material at each of the points of collection also are shown in figure 4. Principal operating data from performance tests for this boiler are given in figure 6.

Pulverized Fuel

A pulverized-fuel system consists basically of a pulverizer to convert the raw coal to powder, a fan to convey it into the furnace, and a burner to mix air and fuel in such a manner as to maintain stable ignition. Pulverized-fuel systems may be arranged as either unit or bin systems. In the bin system the pulverizers are operating independently and at full capacity. Pulverized coal is discharged to a storage hopper, from which it is removed as required. In the unit system one or more machines pulverize and deliver the fuel directly to the burners. Most recent installations are of the unit system, which is simpler, requires less space, creates less fire hazard, and has a lower initial cost than the bin type.

Burners for pulverized fuel may be mounted either horizontally or vertically. The horizontal burners sometimes are made adjustable so that the rate of evaporation in the

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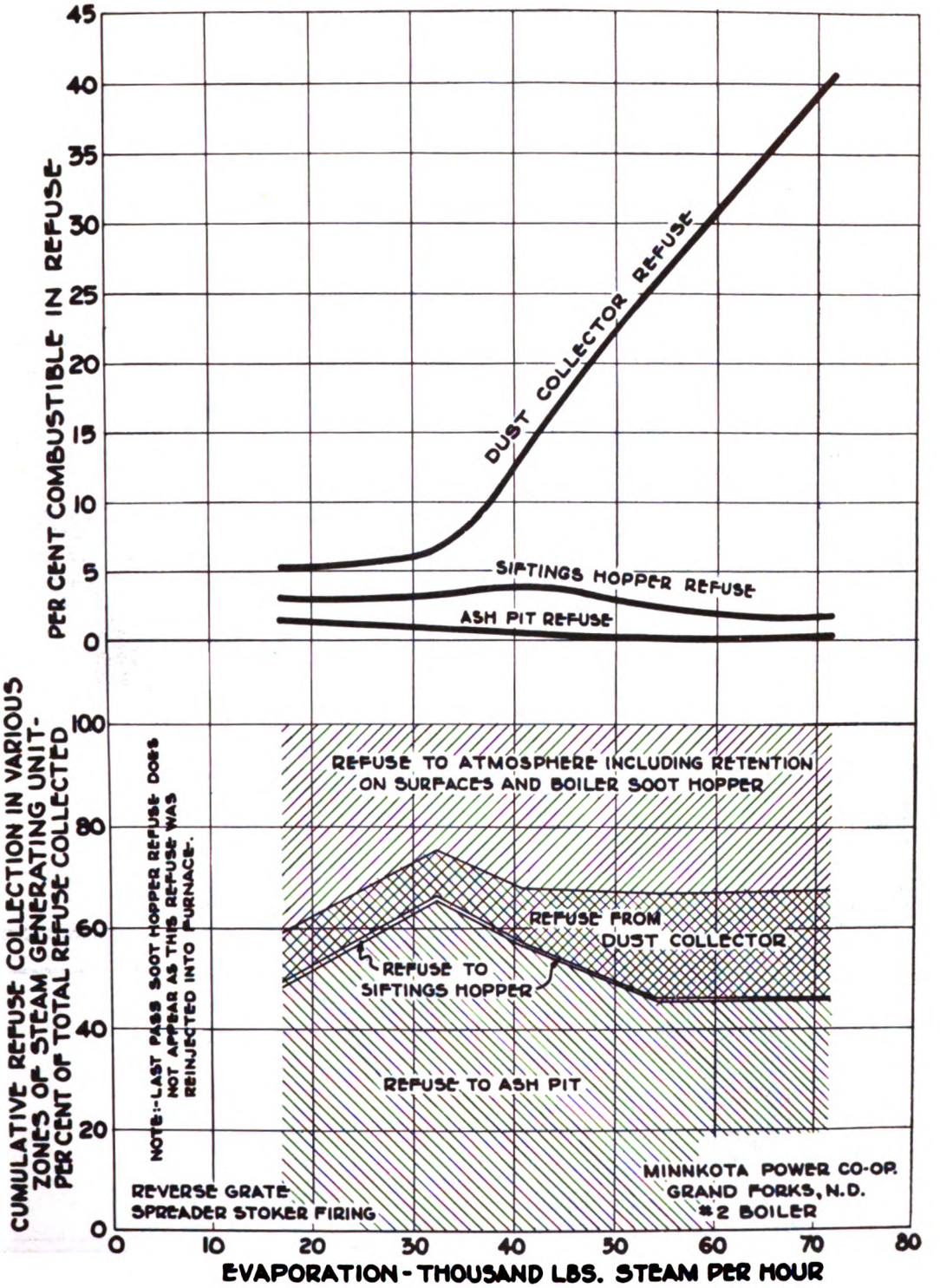

Figure 4. - Percentage distribution of lignite refuse by weight and of combustible in refuse during tests on 72,000-pound-steam-per-hour boiler at the Minnkota station, Grand Forks, N. Dak. See reference (18) in section 1.

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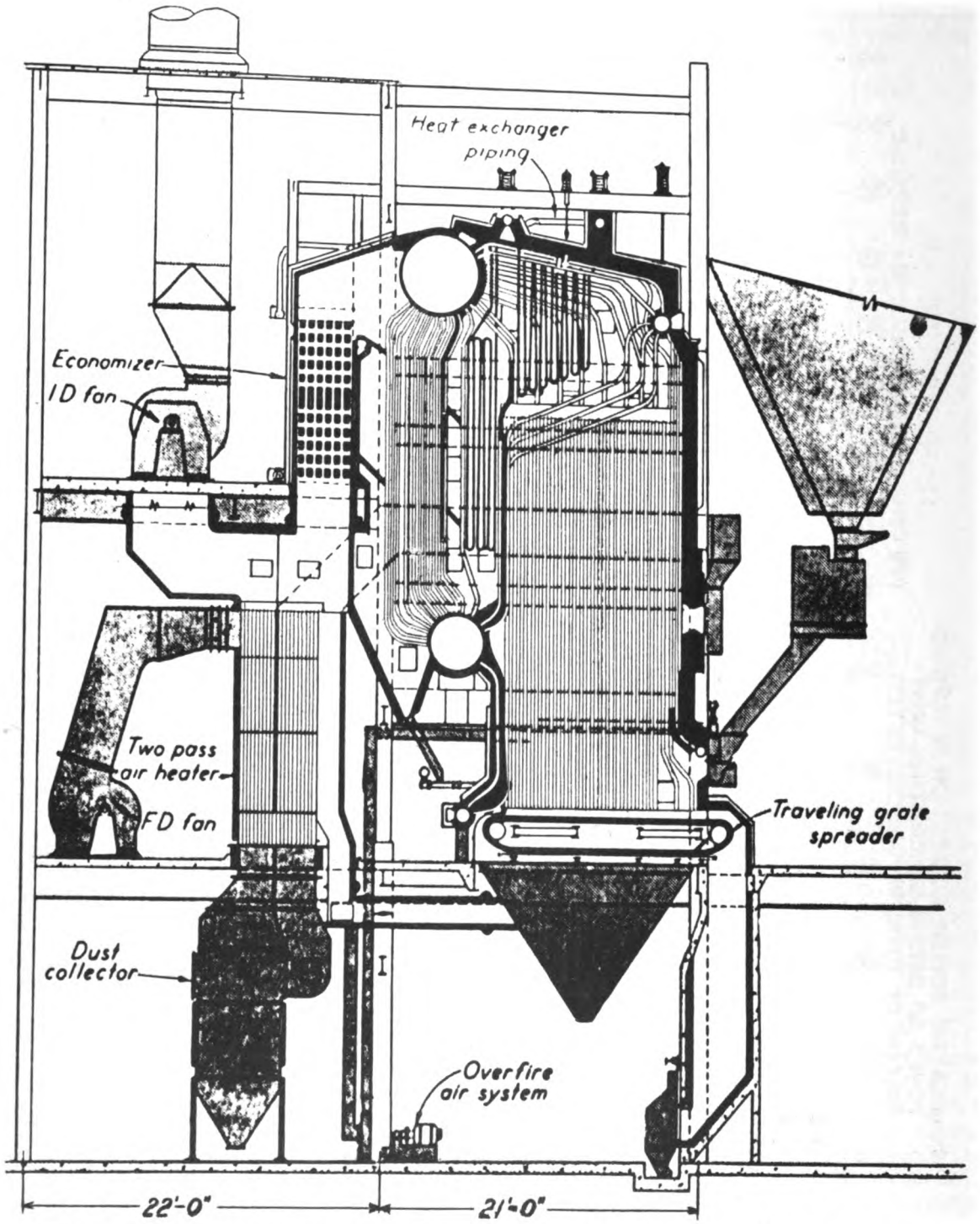

Figure 5. - Spreader stoker-fired steam-generating unit of 72,000-pound-steam-per-hour capacity at the Minnkota station of Minnkota Power Cooperative, Inc., Grand Forks, N. Dak. See reference (12) in section 1.

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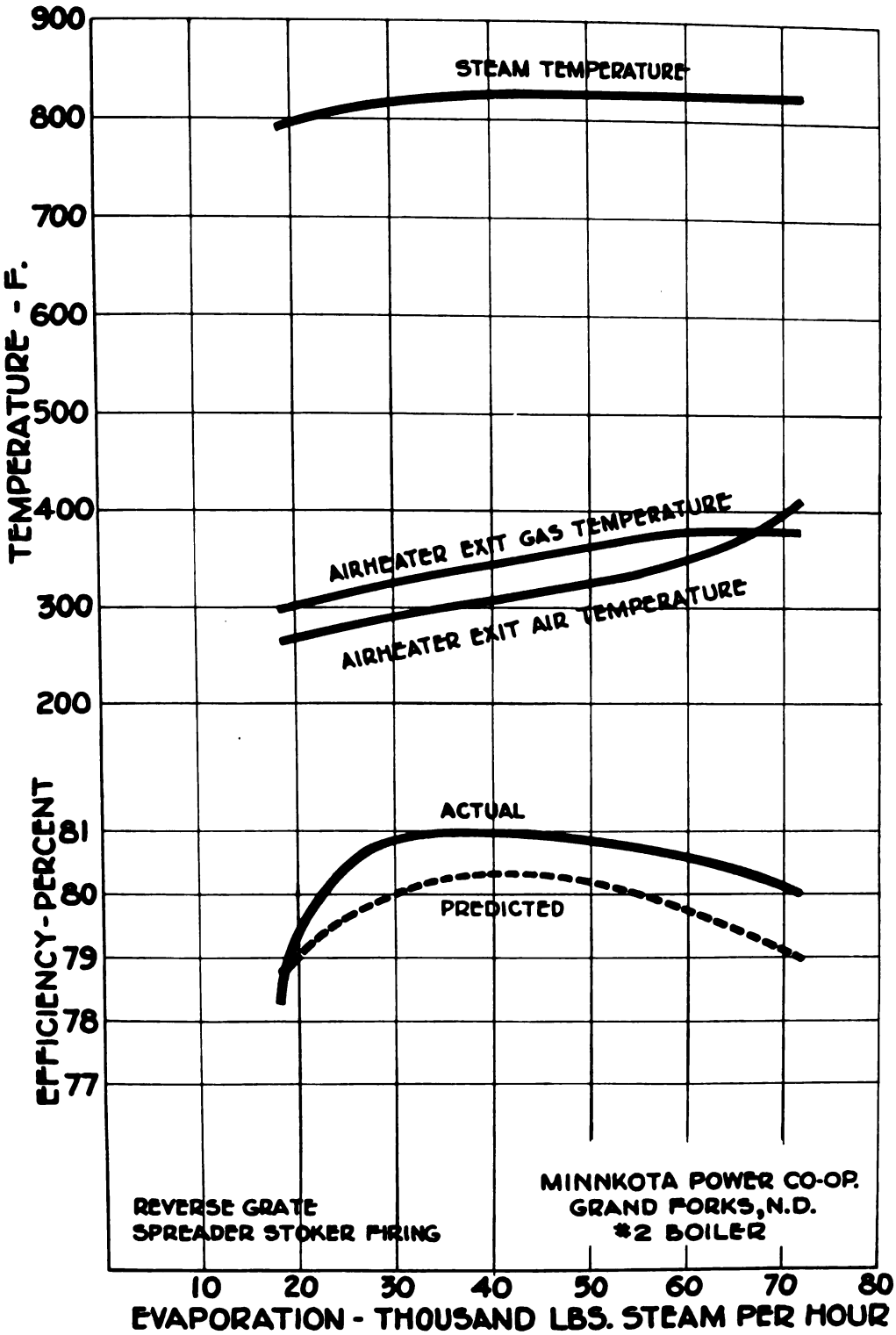

Figure 6. - Operating record for 72,000-pound-steam-per-hour capacity boiler at the Minnkota station, Grand Forks, N. Dak. See reference (12) in section 1. *(By permission of Industry and Power magazine)*

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water walls and the superheat temperature can be controlled by tilting the burners and thereby changing the position of the main flame in the furnace.

Pulverizers are classified as either impact or attrition mills, depending on the method of fuel reduction. The 2 methods may be combined in 1 mill, and lignite can be pulverized successfully by either. It is necessary to reduce the moisture content of the lignite enough to prevent packing and sticking in the mill. With unit pulverizers this is accomplished by introducing high-temperature primary air (600° - 800° F.) into the mills (13, 18). The temperature of the fuel-air mixture from the mill usually is maintained at 130° to 200° F. (13); this discharge from the mill contains water vapor, often near the saturation point, so it is necessary to insulate the duct to the furnace to prevent condensation. This method of pulverizing reduces the total moisture content of the fuel approximately one-third.

Pulverized lignite ignites easily and burns with a stable, relatively short flame. The high percentage of volatile matter and low fixed-carbon content promote rapid ignition, therefore the fineness of pulverization is not as critical with lignite as with other coals. Secondary air for combustion is introduced around the periphery of the burner. Dry-bottom furnaces are used with pulverized lignite firing.

The first successful pulverized-lignite installations in the United States were made in Texas in 1926 (11). In that year 4 boilers, each rated at 185,000 pounds steam per hour, were installed at the Trinidad station of the Texas Power & Light Co. The boilers were of the three-pass, crossdrum design, with interdeck superheaters. At that time mill drying had not been developed. Lignite was predried in steam-heated grid driers before being fed to the mills. Moisture content was reduced from 30 to 33 percent as mined to 25 to 28 percent at the mill. The dried and pulverized fuel was then stored in bins before being fed to the burners. Burners were mounted for vertical firing, and dry-bottom furnaces were used. These units operated at an efficiency of 75.5 percent at full load, with a heat release of 14,600 B.t.u. per cubic foot per hour. Two other similar units were added to the station in 1931. These boilers each had a capacity of 325,000 pounds steam per hour and showed a full-load efficiency of about 76 percent (11), with a furnace heat-release rate of 23,200 B.t.u. per cubic foot per hour.

Other equally successful pulverized-lignite units were operated for a number of years at the Comal station of the San Antonio Public Service Commission (5). These boilers had a rated capacity of 232,000 pounds of steam per hour and were designed for an efficiency of 79.5 percent with a furnace-heat release of 18,400 B.t.u. per cubic foot per hour.

The power stations mentioned above have since been converted to firing other fuels. However, the use of Texas lignite for large steam generators has shown renewed promise recently with installation of the large Texas Power & Light Co. plant at Rockdale, Tex. (16).

The first modern pulverized-fuel installation for North Dakota lignite was installed at the Crookston station (12) of the Otter Tail Power Co. in 1945. (See fig. 7.) The rated capacity of this unit is 75,000 pounds of steam per hour at 425 p.s.i.g. and 825° F. Two unit pulverizers are used to supply fuel to four horizontal burners. The air heater is divided into primary and secondary sections. The total combustion air passes through the secondary heater, after which the steam is divided, about 80 percent being supplied to the burner plenum boxes as secondary air at about 400° F. The other 20 percent is passed through the primary air heater, where the temperature is raised to about 650° F. before it is sent to the pulverizers. The principal operating data (12) for this boiler are shown in figure 2. The satisfactory operation of this plant definitely established that North Dakota lignite was suitable for use in pulverized-fuel installations.

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A series of boiler-performance tests was conducted in 1949 at the Crookston station by the Bureau of Mines, in cooperation with the University of North Dakota and the Otter Tail Power Co. The purpose of the tests was to obtain information on the behavior of steam-dried lignite, as compared with the burning characteristics and efficiency of raw lignite. These comparative tests were run with a boiler load of about 50 percent of rated capacity.

A summary of the test data showed the following difference in operation when burning raw and dried lignite:

1. Boiler efficiency was increased from 76.4 to 81.5 percent when dried lignite was burned (17.8 percent moisture) compared to raw lignite (33 percent moisture).

2. The temperature at the burner outlet, as determined by an optional pyrometer, was approximately 360° F. higher when dried lignite was burned, using an equal percentage of excess air.

3. Steam temperature leaving the superheater was 18° F. lower when the boiler was operated on dried lignite. Less air preheat was used. Although less heat was removed in the superheater and air heater, stack gas temperature was 78° F. lower when dried lignite was burned, indicating that more heat was transmitted by radiation in the main part of the furnace.

The superior combustion characteristics of dried lignite are indicated by these test results. However, such improvements must be balanced against the increased cost of drying when the economics of this type of operation is considered. At present no power plants are using steam-dried lignite.

In general, it has been found that the operating efficiency of pulverized-fuel units is about 2 percent higher than spreader-stoker installations with the same exit-gas temperature (18). Some other advantages of pulverized-fuel firing are: Quick response to load changes, wide range of kinds and quality of coal that may be burned, absence of moving parts in high-temperature inaccessible locations, and the ease with which the boiler can be converted to gas or oil firing. Units of virtually any capacity over 75,000 pounds steam per hour can be fired with pulverized fuel.

The main disadvantage of pulverized-fuel firing, especially with lignite, is the high auxiliary power required for pulverizing. Both the first cost and maintenance are considered to be higher for pulverized-fuel installations than for other methods of firing. For a given capacity boiler, larger pulverizers are required for lignite because of its low heating value. The fibrous nature of lignite also increases grinding difficulty and power required.

The W. J. Neal station (figs. 8 and 9 (6)) of the Central Power Electric Cooperative, Inc., Voltaire, N. Dak., is a good example of modern pulverized-lignite installation. This plant was built in 1951 to meet increasing power demands in western North Dakota and to serve as standby power for Missouri River hydroelectric developments. This plant is only a short distance from several producing lignite mines.

Guaranteed continuous capacity of each of the 2 boilers is 230,000 pounds steam per hour at 865 p.s.i. and 905° F. The maximum 2-hour capacity is 260,000 pounds steam per hour. The plant was designed to burn lignite of the following analysis: Moisture 39.0 percent, ash 6.6 percent, heating value 6,600 B.t.u. per pound (as mined). The boilers are designed for 80-percent efficiency with a heat release of 18,000 B.t.u. per cubic foot per hour. The furnace is of the dry-bottom type and fully

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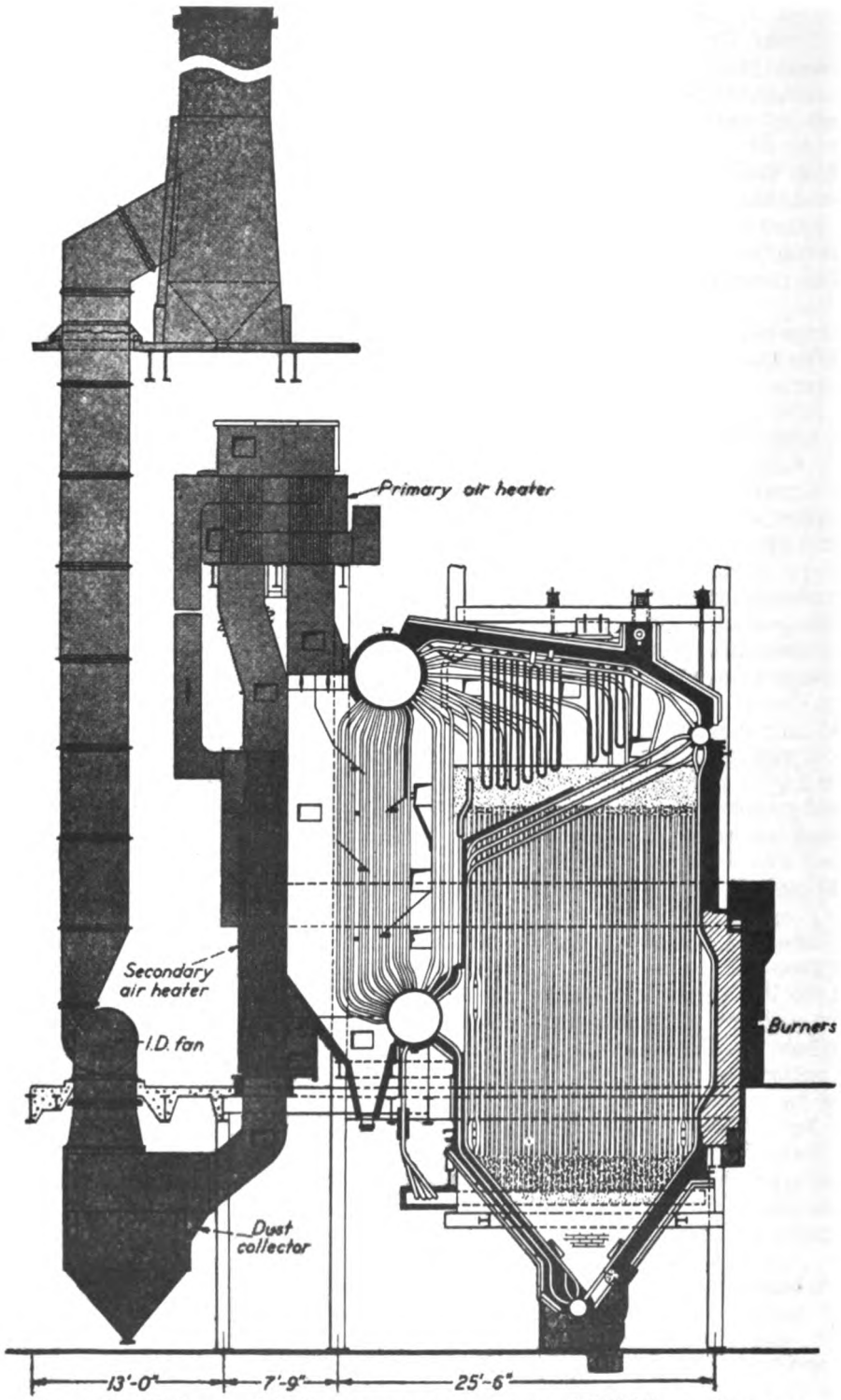

Figure 7. - Pulverized-fuel steam generating unit of 75,000-pound-steam-per-hour capacity at the Crookston station of the Otter Tail Power Co., Crookston, Minn. See reference (12) in section 1.
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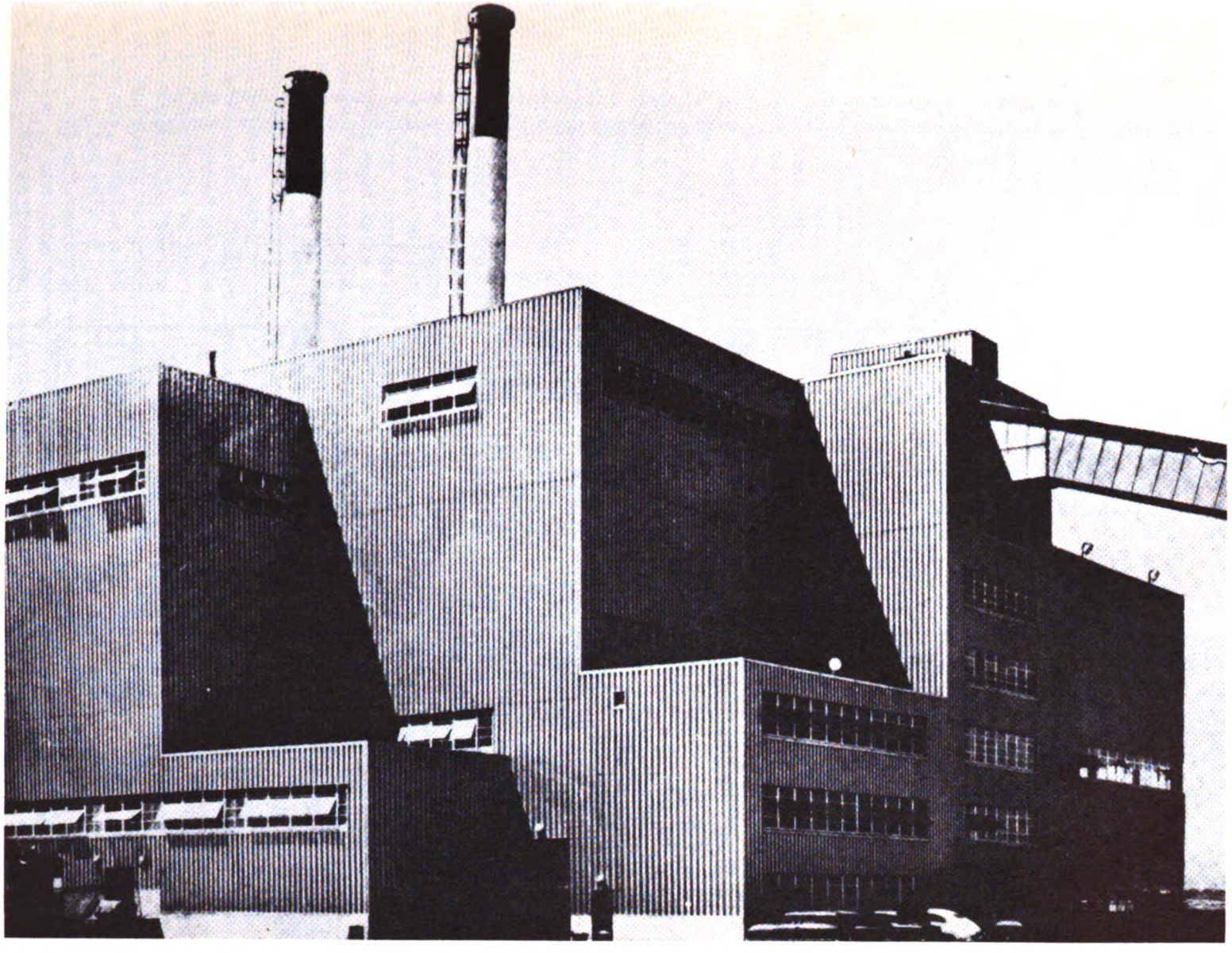

Figure 8. - W. J. Neal station, Voltaire, N. Dak. See reference (6) in section 1. *(By permission of Power magazine)*

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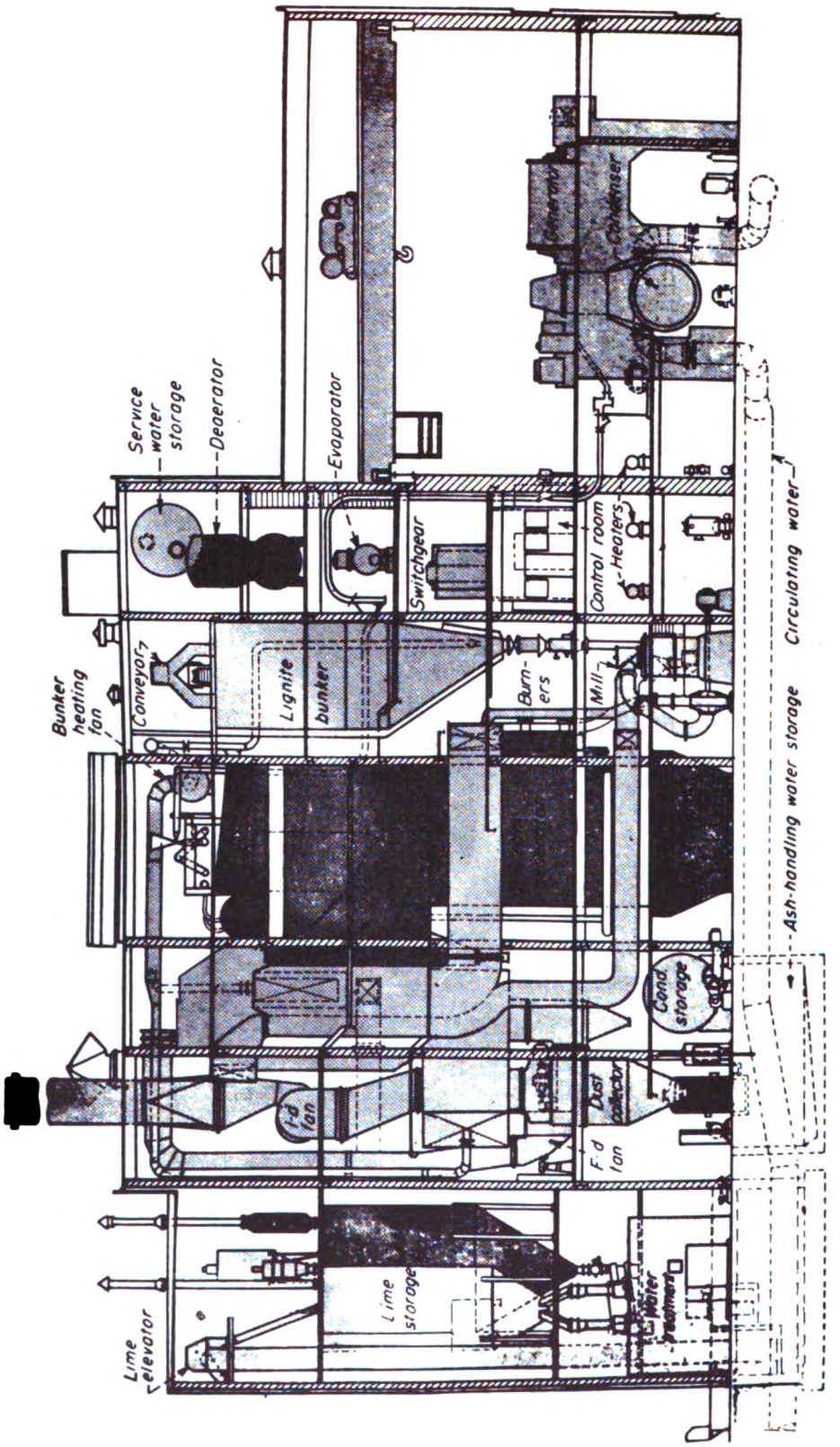

Figure 9. - Cross section of pulverized-fuel installation of 230,000-pound-steam-per-hour capacity at the W. J. Neal station of the Central Power Electric Cooperative, Inc., Voltaire, N. Dak. See reference (6) in section I.
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water cooled. Each boiler has 6 horizontal turbulent-type burners supplied with fuel from 3 bowl-type unit pulverizers. An air preheater supplies air at about 685° F., part of which is used for mill drying in the pulverizers. The fuel-air mixture leaves the pulverizers at about 130° F. Flue gas leaves the furnace at 400° F.

The plant has been operating on a low capacity factor for over a year, and during that time the pulverizers and boilers have given satisfactory performance. Results of a recent test by the boiler manufacturer show that these boilers can be operated with pulverized lignite and satisfactory ignition maintained at less than one tenth of rated capacity.

Operating data for the Neal station for 1952 are listed in table 2. These data are taken from a summary sheet of operating data from selected cooperatives compiled by the United States Department of Agriculture.

TABLE 2. - Summary of operating data, 1952, W. J. Neal station, Central Power Electric Cooperative, Voltaire, N. Dak.

Fuel cost.....cents per million B.t.u.	17
Boiler efficiency.....percent	76
Station heat rate.....B.t.u. per net kw.-hr.	14,500
Station consumption.....percent of gross power generated	11.7
Plant factor.....percent	34
Running plant capacity factor.....do.	63
Fuel cost.....mills per net kw.-hr.	2.54
Operating labor cost.....do.	1.04
Maintenance cost.....do.	0.26
Miscellaneous cost.....do.	0.36
Total production cost.....do.	4.20
Station heat rate, best month.....B.t.u. per net kw.-hr.	14,058
Boiler efficiency, best month.....percent	80

Cyclone Burners

Cyclone burners are the most recent development in coal-burning equipment. They are essentially water-cooled, cylindrical, combustion chambers, the inside of which is lined with a plastic chrome refractory. Crushed coal and primary air are introduced tangentially at one end of the burner. Fuel and air are thus given a whirling motion, which is further increased by tangential introduction of secondary air. Tertiary air is admitted tangentially at the outer end of the burner, causing the mixture to move in an increasing helix toward the main furnace. Combustion of the fuel is completed as it moves through the burner, leaving most of the molten ash adhering to the cylinder wall, from where it flows to the slag tank. The nature of this burning tends to reduce substantially the amount of ash carried in suspension, hence fly-ash emission is low. The axis of the burner is tilted downward at the furnace end to facilitate discharge of the molten ash. Combustion gases pass into the main furnace through a reentrant water-cooled throat at the discharge end of the burner and then pass over the heat-absorbing surfaces in the boiler. After a molten-slag coating has been established on the burner wall, the larger particles of the incoming fuel are forced against the sticky surface by centrifugal force and thereafter move with the slag at a slower rate than the air, causing a violent scrubbing action between the coal and air. This action accelerates the rate of combustion. Burning rates as high as 400,000 B.t.u. per cubic foot per hour and temperatures over 3,000° F. (9) are developed in the cyclone burner. Preparation of coal for use in a cyclone burner consists of crushing to a size of about 1/4-inch. This represents a substantial reduction of auxiliary power over that required

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for pulverized firing. However, the forced-draft-fan power requirements are large with cyclone firing because air is supplied to the burner at a pressure of about 35 inches H_2O. This pressure is required to obtain satisfactory velocities in the burner. The cyclone burner has been successfully used with a large number of coals, as well as with oil and gas.

Cyclone firing was developed to obtain a better method for burning coals with high ash content and low ash-fusion temperature. Pilot-plant models were constructed and tested before 1940 (10). A developmental installation was made at the Calumet station (fig. 10) of the Commonwealth Edison Co. in 1944. Since then this method of firing has been installed in a number of large midwestern (20) power plants.

In May 1949 tests were conducted at the Calumet station of the Commonwealth Edison Co., Chicago, Ill., using North Dakota lignite in an 8-foot-diameter nearly horizontal cyclone burner. The rated capacity of the boiler was 180,000 pounds steam per hour at 350 p.s.i. and 650° F. steam. The following information is taken from a description by Hoffman and Drabelle (13) of the test conditions and results.

> The high moisture content caused some ignition difficulties in the early part of the tests, but these were overcome by burning natural gas in the primary air line to the crusher, thereby raising the air temperature to the crusher from approximately 425° F. to 650° F.
>
> Rates up to 170,000 pounds of steam per hour were carried with satisfactory operating conditions. Excess air leaving the cyclone was varied from approximately 5 to 30 percent to study the effect on combustion and slag tapping. During periods of operation with low excess air, only fine sparklers, similar to those which might have occurred from burning paper, were observed in the primary furnace, and slag from the tap was quite fluid. There was no smoke at any time firing this fuel. During periods of operation with high excess air, the slag in the primary furnace was somewhat more viscous, and occasional large flakes of lignite could be seen on the primary furnace floor. In general the slag behavior was similar to that of the normally-burned Illinois No. 6 bed coal, but perhaps slightly more viscous.
>
> The test results can be summarized as follows:
>
> 1. This lignite can be successfully burned in the cyclone furnace.
>
> 2. Primary air temperature of around 650° F. is required to provide the necessary drying to give good ignition.
>
> 3. Slag behavior is similar to that of Illinois No. 6 bed coal, although the slag may be a little more viscous.
>
> 4. The crushing characteristics are somewhat different from those of other coals burned, the crushed product being coarser and more flaky.
>
> 5. There is no smoke discharge from the stack regardless of excess air.
>
> 6. To eliminate the need for pre-drying equipment, a cyclone-furnace-fired unit designed for burning this lignite should be arranged for direct firing to permit drying in the crusher.

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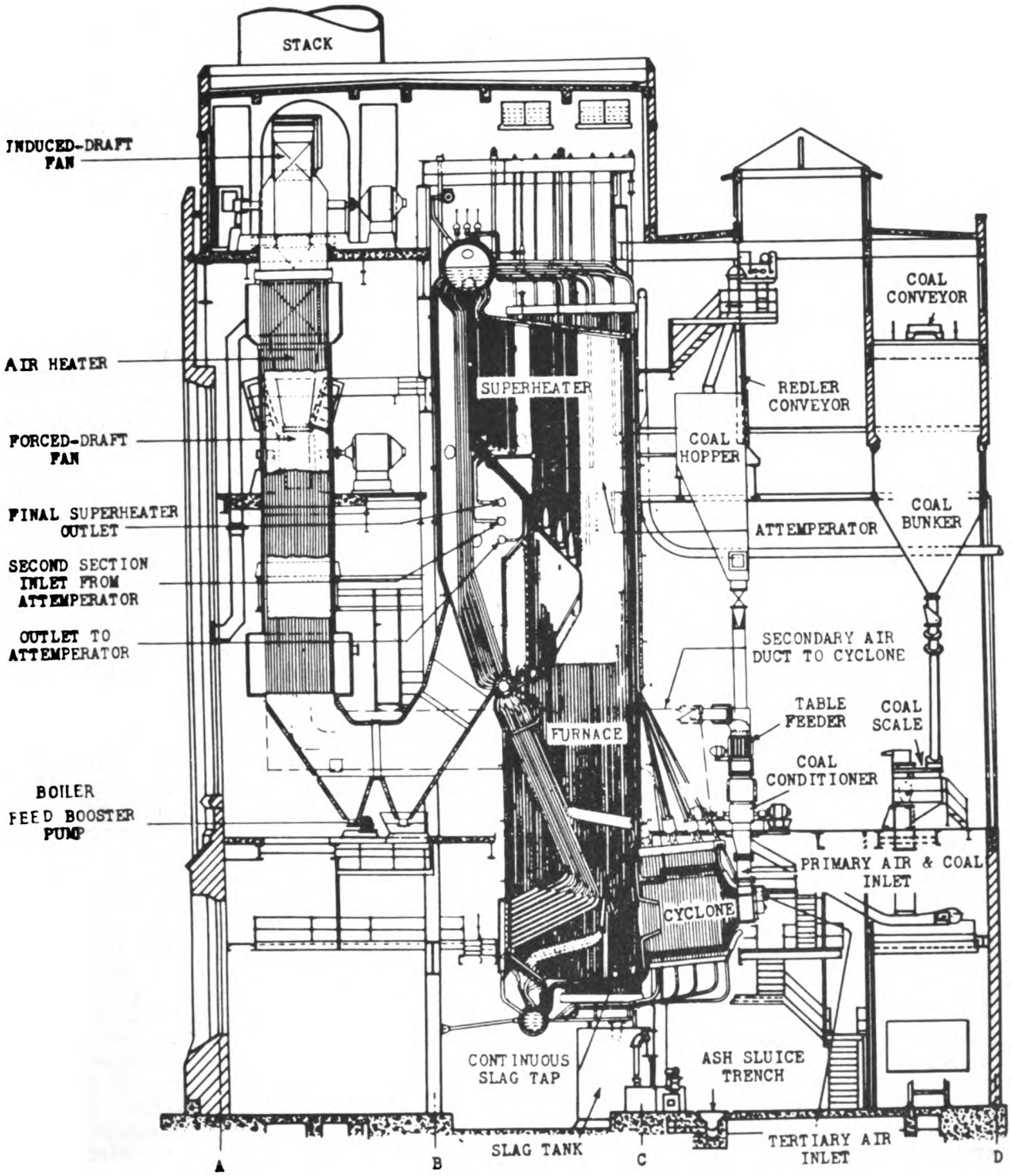

Figure 10. - Cyclone burner-fired steam-generating unit of 180,000-pound-steam-per-hour capacity at the Calumet station of the Commonwealth Edison Co., Chicago, Ill. See reference (13) in section 1. *(By permission of Am. Soc. Mech. Eng.)*

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for pulverized firing. However, the forced-draft-fan power requirements are large with cyclone firing because air is supplied to the burner at a pressure of about 35 inches H_2O. This pressure is required to obtain satisfactory velocities in the burner. The cyclone burner has been successfully used with a large number of coals, as well as with oil and gas.

Cyclone firing was developed to obtain a better method for burning coals with high ash content and low ash-fusion temperature. Pilot-plant models were constructed and tested before 1940 (10). A developmental installation was made at the Calumet station (fig. 10) of the Commonwealth Edison Co. in 1944. Since then this method of firing has been installed in a number of large midwestern (20) power plants.

In May 1949 tests were conducted at the Calumet station of the Commonwealth Edison Co., Chicago, Ill., using North Dakota lignite in an 8-foot-diameter nearly horizontal cyclone burner. The rated capacity of the boiler was 180,000 pounds steam per hour at 350 p.s.i. and 650° F. steam. The following information is taken from a description by Hoffman and Drabelle (13) of the test conditions and results.

> The high moisture content caused some ignition difficulties in the early part of the tests, but these were overcome by burning natural gas in the primary air line to the crusher, thereby raising the air temperature to the crusher from approximately 425° F. to 650° F.
>
> Rates up to 170,000 pounds of steam per hour were carried with satisfactory operating conditions. Excess air leaving the cyclone was varied from approximately 5 to 30 percent to study the effect on combustion and slag tapping. During periods of operation with low excess air, only fine sparklers, similar to those which might have occurred from burning paper, were observed in the primary furnace, and slag from the tap was quite fluid. There was no smoke at any time firing this fuel. During periods of operation with high excess air, the slag in the primary furnace was somewhat more viscous, and occasional large flakes of lignite could be seen on the primary furnace floor. In general the slag behavior was similar to that of the normally-burned Illinois No. 6 bed coal, but perhaps slightly more viscous.
>
> The test results can be summarized as follows:
>
> 1. This lignite can be successfully burned in the cyclone furnace.
>
> 2. Primary air temperature of around 650° F. is required to provide the necessary drying to give good ignition.
>
> 3. Slag behavior is similar to that of Illinois No. 6 bed coal, although the slag may be a little more viscous.
>
> 4. The crushing characteristics are somewhat different from those of other coals burned, the crushed product being coarser and more flaky.
>
> 5. There is no smoke discharge from the stack regardless of excess air.
>
> 6. To eliminate the need for pre-drying equipment, a cyclone-furnace-fired unit designed for burning this lignite should be arranged for direct firing to permit drying in the crusher.

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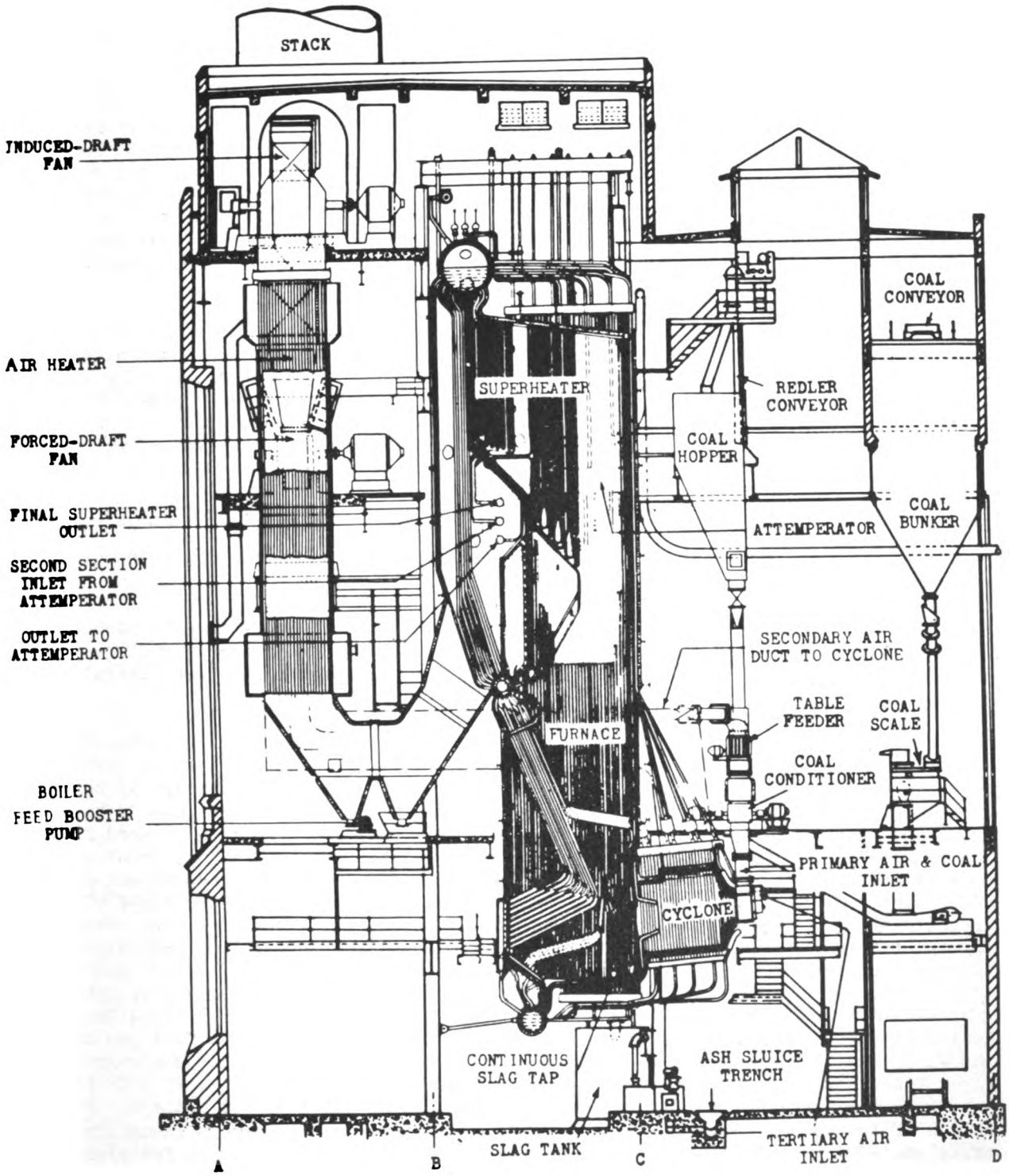

Figure 10. - Cyclone burner-fired steam-generating unit of 180,000-pound-steam-per-hour capacity at the Calumet station of the Commonwealth Edison Co., Chicago, Ill. See reference (13) in section 1. *(By permission of Am. Soc. Mech. Eng.)*

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7. Although dust loading tests were not conclusive, indications were that ash discharge from the stack was somewhat lower than when burning Illinois No. 6 bed coal.

Cyclone-furnace-fired boilers have shown high efficiencies owing to the low excess air and the low combustible loss in the ash. Only about 10 percent of the total ash content of the fuel enters the main furnace. This can be compared with an average figure of 50 percent for a wet-bottom pulverized-fired furnace and 80 percent for a dry-bottom furnace. Results of cyclone-burner tests using Illinois coal (20) have shown no reduction in equipment, or labor for cleaning the heat-absorbing surfaces, however, because the dust that is carried over is of such a composition that it sticks to the surfaces. Much smaller dust collectors are required for this method of firing. The combined slag- and ash-handling system is, however, more complicated for cyclone-burner firing than for pulverized-fuel firing.

According to Schroeder and Stasser (20), a cyclone-fired boiler requires approximately 10 percent less floor space and 25 percent less volume than a comparable pulverized-fuel installation. Some other advantages are low cost of preparing the fuel and low maintenance cost on burner because of the lack of moving parts. In some installations the induced draft fan has also been eliminated. The cyclone burner has been used successfully with units as small as 180,000 pounds of steam per hour, and it appears to be applicable to virtually any larger size installation.

Comparative Survey of Steam Power Plants Burning North Dakota Lignite

Table 3 lists the lignite-burning steam power plants in North Dakota, South Dakota, and Minnesota (2, 12).

It should be noted from table 3 that lignite-fired boilers have followed the industry-wide trend of using increasingly higher operating temperatures and pressures. It is also significant to note the large number of boilers that have been installed since 1947.

Boiler, furnace, and stoker data (2, 12) for 15 of the larger lignite-burning boilers are listed in table 4. The data listed are design or specification information in all instances and not test or operating data. The boilers listed range in capacity from 60,000 to 230,000 pounds of steam per hour, and all except the Fargo unit have been installed since 1947. Open-type complete water-wall construction is used for all the recent installations, except the Bison unit, which uses a refractory front wall. Air heaters are used in all the installations listed except Fargo, but economizers are used with only 5 of the 15 boilers listed. Twelve of the boilers listed are fired with spreader stokers, 2 with unit pulverizers, and 1 with a chain-grate stoker. The popularity of spreader stokers is quite obvious. However, the Ortonville plant approaches the maximum size unit now considered adaptable for use with them. The unit pulverizer method was chosen for the larger W. J. Neal station, and future boilers over 250,000 pounds steam per hour will probably be fired with unit pulverizers or cyclone burners. Heat release for the units listed varies from 18,000 B.t.u. per cubic foot per hour for the W. J. Neal boiler to 35,600 B.t.u. per cubic foot per hour for the chain-grate-fired Kidder station. Preheated air temperatures ranging from 350° F. to 450° F. are used with the spreader stokers and 675° to 700° F. with the unit pulverizers. The boiler efficiencies listed, which range from 73 to 80 percent, compare favorably with efficiencies for similar boilers fired with other coals after adjusting for higher flue-gas loss due to evaporation of the moisture content of the fuel.

Comparative data on heat releases for boilers burning bituminous coal and lignite are presented in table 5 (2, 12).

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TABLE 3.—Lignite-burning power plants in North Dakota, South Dakota, and Minnesota

No. boilers alike	Year built	Plant	Name of company	Steam generating capacity, lb./hr.	Steam pressure, psi.	Steam temperature, °F.
2	1951	Wm. J. Neal, Voltaire, N.D.	Central Power Cooperative	230,000	865	905
	1951	Minnkota, Grand Forks, N.D.	Minnkota Power Cooperative, Inc.	135,000	615	825
	1950	Ortonville, Minn.	Ottertail Power Co.	160,000	865	900
	1950	Grand Forks, N.D.	Northern States Power Co.	75,000	425	750
	1950	Minnkota, Grand Forks, N.D.	Minnkota Power Cooperative, Inc.	72,000	615	825
	1950	Valley City, N.D.	Municipal Utility	50,000	425	750
2	1950	Mobridge, S.D.	Montana-Dakota Utilities Co.	50,000	415	750
	1949	Kidder, Wahpeton, N.D.	Otter Tail Power Co.	100,000	600	825
	1949	Devils Lake, N.D.	Otter Tail Power Co.	100,000	400	750
	1949	Fargo, N.D.	Northern States Power Co.	75,000	425	750
	1949	Bison, Minot, N.D.	Northern States Power Co.	75,000	420	750
	1949	Crookston, Minn.	Otter Tail Power Co.	75,000	400	825
	1949	Minnkota, Grand Forks, N.D.	Minnkota Power Cooperative, Inc.	72,000	615	825
2	1949	Beulah, N.D.	Montana-Dakota Utilities Co.	50,000	400	750
	1949	Moorhead, Minn.	Public Service Dept.	45,000	400	750
	1948	Jamestown, N.D.	Otter Tail Power Co.	100,000	600	825
	1948	Hoot Lake, Fergus Falls, Minn.	Otter Tail Power Co.	95,000	400	825
	1948	Grand Forks, N.D.	Northern States Power Co.	75,000	425	750
	1948	Crookston, Minn.	Otter Tail Power Co.	75,000	400	825
	1948	Bismarck, N.D.	Montana-Dakota Utilities Co.	60,000	450	750
	1948	Kincaid, N.D.	Montana-Dakota Utilities Co.	60,000	250	545
	1947	Devils Lake, N.D.	Otter Tail Power Co.	75,000	400	750
	1946	Moorhead, Minn.	Public Service Dept.	45,000	400	750
2	1945	Aberdeen, S.D.	Northwestern Public Service Co.	45,000	625	850
	1945	Washburn, N.D.	Otter Tail Power Co.	40,000	250	610
2	1940	Valley City, N.D.	Municipal Utility	40,000	425	625
	1939	Fargo, N.D.	Northern States Power Co.	100,000	425	750
	1938	Fargo, N.D.	Northern States Power Co.	50,000	225	525
2	1938	Bismarck, N.D.	Montana-Dakota Utilities Co.	30,000	450	750
	1937	Kidder, Wahpeton, N.D.	Otter Tail Power Co.	100,000	800	825
	1937	Grand Forks, N.D.	Northern States Power Co.	65,000	200	525
	1937	Beulah, N.D.	Montana-Dakota Utilities Co.	50,000	265	600
	1936	Minot, N.D.	Northern States Power Co.	54,000	200	505
	1936	Valley City, N.D.	Municipal Utility	35,000	275	500
	1936	Moorhead, Minn.	Public Service Dept.	17,500	400	750
2	1932	Grand Forks, N.D.	Northern States Power Co.	45,000	200	525
2	1932	Kincaid, N.D.	Montana-Dakota Utilities Co.	25,000	250	530
	1930	Minot, N.D.	Northern States Power Co.	32,000	200	505
	1929	Fargo, N.D.	Northern States Power Co.	110,000	225	525
	1929	Washburn, N.D.	Otter Tail Power Co.	40,000	250	610
2	1929	Harvey, N.D.	Otter Tail Power Co.	23,000	230	610
	1928	Beulah, N.D.	Montana-Dakota Utilities Co.	50,000	285	600
	1928	Grand Forks, N.D.	Northern States Power Co.	45,000	200	525
2	1928	Jamestown, N.D.	Otter Tail Power Co.	30,000	200	500
	1927	Fargo, N.D.	Northern States Power Co.	110,000	225	525
	1927	Kidder, Wahpeton, N.D.	Otter Tail Power Co.	70,000	300	625
	1927	Beulah, N.D.	Montana-Dakota Utilities Co.	50,000	265	600
	1927	Bismarck, N.D.	Montana-Dakota Utilities Co.	40,000	180	460
2	1926	Washburn, N.D.	Otter Tail Power Co.	40,000	250	610
	1923	Fargo, N.D.	Northern States Power Co.	32,000	225	525
	1920	Aberdeen, S.D.	Northwestern Public Service Co.	60,000	250	600
	1920	Aberdeen, S.D.	Northwestern Public Service Co.	35,000	250	680
2	1915	Minot, N.D.	Northern States Power Co.	20,000	165	525
2	1910	Minot, N.D.	Northern States Power Co.	20,000	165	525
	1910 1/	Harvey, N.D.	Otter Tail Power Co.	45,000	230	550

1/ Rebuilt in 1942.

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TABLE 4.--Boiler, furnace, and stoker data for the larger steam-generating plants firing lignite 1/

Plant	Capacity, lb. steam per hr.	Year built	Pressure, psi.	Temperature, °F.	Chamber construction	Heating surfaces, sq.ft.					Furnace vol., cu. ft.	Grate area, sq. ft.	Lb. lignite per hour	Heat release (based on 6600 B.t.u./lb. lignite)		Type stoker	Type grate	Type ash disposal	Primary air temp., °F.	Maximum efficiency, %
						Boiler	W.W.	S.H.	Econ.	A.H.				B.t.u./cu.ft. per hour	B.t.u./sq.ft./hr.					
Wm. Neal, Voltaire, N.D.	230,000	1951	865	905	W.W.	13,610	9,615	6,600	None	58,400	17,200	None	47,000	18,000	-	Pulverized coal fired		P.	675	80
Ortonville, Minn.	160,000	1950	865	900	W.W.	16,250	4,230	4,780	6,100	17,200	12,250	446	37,200	20,000	550,000	Sp.	T.	P.	370	79
Minnkota, Grand Forks, N.D.	135,000	1950	615	825	W.W.	14,950	1,825	5,370	4,620	16,890	7,750	392	27,000	23,000	455,000	Sp.	T.	P.	360	80
Fargo, N.D.	110,000	1939	225	525	R.W.	11,510	-	-	None	None	-	284	19,900	-	463,000	Sp.	D.	P.	Room temp.	-
Kidder, Wahpeton, N.D.	100,000	1949	600	825	W.W.	9,500	2,200	-	2,400	13,000	4,100	316	22,100	35,600	462,000	C.G.	T.	H.	360	79
Devils Lake, N.D.	100,000	1948	400	750	W.W.	10,435	2,460	-	None	9,450	7,660	304	22,400	19,300	487,000	Sp.	T.	P.	375	75
Jamestown, N.D.	100,000	1948	600	825	W.W.	12,670	2,195	-	None	-	6,150	288	22,200	23,800	508,000	Sp.	T.	P.	350	77
Hoot Lake, Fergus Falls, Minn.	95,000	1948	400	825	W.W.	10,170	2,436	-	1,850	4,330	6,500	253	21,300	21,000	540,000	Sp.	T.	P.	375	77
Moorhead, Minn. 2/	90,000	1948	410	550	W.W.	16,950	2,673	-	None	8,600	6,840	235	24,000	23,100	673,000	Sp.	T.	P.	360	-
Crookston, Minn.	75,000	1948	400	825	W.W.	7,550	3,400	1,630	None	11,600	5,430	None	18,300	22,300	-	Pulverized coal fired		P.	706	78.5
Crookston, Minn.	75,000	1949	400	825	W.W.	9,250	2,025	-	None	6,300	4,800	195	16,800	23,200	570,000	Sp.	T.	P.	350	77.5
Grand Forks, N.D.	75,000	1950	425	750	W.W.	8,350	-	1,730	None	5,800	4,195	230	17,000	26,700	487,000	Sp.	T.	P.	350	74
Bison, Minot, N.D.	75,000	1948	420	750	W.W. except front	8,150	1,160	-	None	5,800	4,195	230	16,800	26,400	483,000	Sp.	T.	H.	350	73
Minnkota, Grand Forks, N.D.	72,000	1950	615	825	W.W.	7,650	-	2,510	2,125	8,590	4,000	168	15,300	25,200	602,000	Sp.	T.	P.	360	78
Kincaid, N.D.	60,000	1948	250	545	W.W.	6,999	1,051	-	None	-	3,250	163	13,500	27,400	546,000	Sp.	T.	P.	450	77

1/ Data in each case are for single boilers, and do not necessarily represent total plant capacity.
2/ American Crystal Sugar Plant.

Abbreviations: W.W. - Water wall
Sp. - Spreader
D. - Dump
P. - Pneumatic
R.W. - Refractory wall
C.G. - Chain grate
T. - Traveling
H. - Hydraulic
S.H. - Superheater
A.H. - Airheater

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TABLE 5. - Comparative heat-release rates for boilers burning lignite and bituminous coal

Fuel and firing equipment	No. of boilers	Capacity, pounds of steam/hr.	Firing rate, pounds/ sq.ft. grate/hr.	Heat release	
				B.t.u./ cu.ft./ hr.	B.t.u./ sq.ft. grate/hr.
Plants burning lignite:					
A. Traveling grate.....	6	36,700	62.1	35,100	416,833
B. Spreader stoker.....	21	73,000	76.9	27,029	562,333
C. Pulverizer.....	2	-	-	20,767	-
Plants burning bituminous coal:1/					
A. Traveling grate.....	2	85,000	35.9	35,956	450,000
B. Spreader stoker.....	25	63,000	36.5	26,248	465,000
C. Pulverizer.....	29	-	-	21,048	-

1/ Toby, T. S., Data from New Steam Generators in Pulp and Paper Industry: Utilization, No. 12, 1948, p. 17.
Information on bituminous firing was taken from this source to provide information on boilers of capacities similar to those of the lignite-burning units.

It will be noted that the performance of lignite-burning boilers is very similar to that of bituminous-burning boilers, with the exception of the pounds of coal per hour per square foot of grate area. This value is larger with lignite because of its lower heating value. On the basis of the data presented in table 5, the average heat release rate for the lignite-fired boilers about equals that of similar units burning bituminous coal. However, the respective boiler efficiencies are not considered in this listing. To obtain maximum efficiency, lignite furnaces are generally built higher and have somewhat greater volume per unit capacity than bituminous furnaces.

Selected operating data (2, 12) for 1950 of plants fired with North Dakota, lignite are shown in table 6. These plants were chosen for study because, unlike many of the other plants in table 3, they do not supply steam for heating purposes outside the plant.

It will be noted that the B.t.u. per kilowatt-hour net for the plants listed ranges from 14,800 for the new Minnkota plant to 38,613 for the older Harvey station. In general, the newer plants show better heat rates than the older units. However, the plant-capacity factor probably has more effect on the B.t.u. per kilowatt-hour than any other single factor. If boilers are operated on banked conditions or at low loads for a considerable part of the time the heat rate will be high. The average boiler efficiency and average plant efficiency are similarly affected by a low capacity factor. The percentage of generated output required for station power for the plants listed varies from about 5 to 12 percent. This ratio is, of course, higher for pulverized fuel installations and again the capacity factor has considerable influence.

A comparison of boiler efficiencies of lignite-fired power plants and modern bituminous-fired power plants operating with a high plant factor indicates that station heat rates as low as 11,500 B.t.u. per net kilowatt hour seem feasible with a lignite-burning installation operating with a comparable high plant factor.

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TABLE 6. - Operating data for plants fired with lignite[1]

Plant	Year first boiler installed	Electrical generating capacity in kw.	Net kw.-hr. generated in 1950	Average B.t.u. per net kw.-hr.	Type[2] stoker	Station power ave., %	Average boiler efficiency, %	Average plant efficiency, %	Plant capacity factor, %
Beulah, N. Dak.	1919	13,500	64,587,596	23,537	CG+Sp.	8	72	14.5	54.6
Aberdeen, S. Dak.	1920	13,500	70,379,200	21,200	T.G.	9	78	17	59.5
Ortonville, Minn.	1950	15,000	7,073,000	15,500	Sp.	5	79	25 [3]	12.8 [3]
Kidder (low press.) Wahpeton, N. Dak.	1927	10,500	82,411,000	23,500	C.G.	9	57	15	45.8
Kidder (high press.)	1937	10,000		17,000	C.G.	3	79	20	
Moorhead, Minn.	1936	8,250	23,877,700	21,700	Sp.	7	80	16	33.0
Fargo, N. Dak. (high press.)	1939	10,000		18,459	Sp.	6	74	18.5	
Crookston, Minn.	1948	10,000	49,688,000	16,553	Sp.+P.	10	77	20.7	56.6
Minnkota, Grand Forks, N. Dak.	1950	10,000 [4]	72,600,000	14,800	Sp.	7	78	21	82.8
Harvey, N. Dak.	1924	5,000	16,499,000	38,615	C.G.+Sp.	12	55	8.9	37.7
Kincaid, N. Dak.	1928	6,000	24,923,669	35,294	C.G.+Sp.	11	75	9.7	47.4
Washburn, N. Dak.	1926	8,000	54,289,000	24,999	C.G.	7	70	13.7	77.4

1/ Source, references (2)(12).

2/ Abbreviations:
P. —Pulverized coal fired
Sp. —Spreader
C.G.—Chain grate
T.G.—Traveling grate

3/ Plant new - in operation about 5 months.

4/ New 11,500 kw. generator added March 1951.

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Construction and Electrical Production Costs for Lignite-Burning Power Plants

The construction and electrical production cost for some of the larger lignite-burning power plants in North Dakota and Minnesota are listed in table 7 (2, 12).

TABLE 7. - Selected lignite power plants, production and operating costs

Plant	Year built	Generating capacity in kw.	Construction cost per kw.	Production cost, mills/kw.-hr.		
				Labor and Miscellaneous	Fuel	Total
Ortonville, Minn.	1950	15,000	219	1.16	5.80	6.96
Hoot Lake, Fergus Falls, Minn. ..	1948	7,500	232	2.14	5.44	7.58
Crookston, Minn..	1948-49	10,000	317	2.12	5.85	7.97
Minnkota, Grand Forks, N. Dak..	1944-51	21,500	194	1.57	4.60	6.17
Devils Lake, N. Dak.	1947-49	12,500	248	-	-	7.27
Bison, Minot, N. Dak.	1949	4,000	528	2.58	4.06	6.64
W. Neal, 1/ Voltaire, N. Dak.	1950	45,000	189	1.66	2.54	4.20

1/ Data taken from a summary sheet of operating data from selected cooperatives compiled by the U. S. Department of Agriculture.

Construction costs for the Bison and Crookston plants are unusually high because in each instance building and other provisions were made for the future addition of units that could greatly expand the present installed capacity. Of interest is the decrease in construction cost per kilowatt as the plant capacity increases. The construction cost of $189 per kilowatt for the Neal station is indicative of the manner in which costs can be reduced with large central power stations.

In 1951 the Vern E. Alden Co. (3), Chicago engineering firm, prepared studies of the construction and operational cost for several proposed large power plants utilizing lignite. It estimated that a private company would require $120,000,000 capital to build a plant of 800,000 kilowatts capacity. This would be a unit cost of $150 per kilowatt. This plant would burn pulverized fuel. Alternate plans were worked out by Alden for plants of 800,000 and 240,000 kilowatts, respectively, using char from a low-temperature-carbonization process like that to be used at the Texas Power & Light Alcoa plant (16) in Milam County, Tex. The construction cost estimated for the smaller unit was about $200 per kilowatt because of increased investment required for the carbonization plant.

The cost of producing power is primarily a function of the fuel cost. Therefore, plants at the mine mouth can effect a substantial savings by eliminating freight costs. This is shown in table 7, listing production costs for selected plants burning lignite. The Ortonville, Hoot Lake, and Crookston plants are near the eastern boundary of the geographical area of economical use of lignite as a fuel (fig. 37, part 1), and as such their coal costs are high.

The Alden Co. estimated a production cost, including overhead and fixed charges, of 2.86 mills per kilowatt-hour for a 800,000-kw. station using raw lignite. This was

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based on a coal cost of 1.15 dollars per ton and a 95-percent load factor. Production costs were also worked out for plants using low-temperature carbonization for recovery of byproduct chemicals. However, the basis of this calculation was that North Dakota lignite would produce about 15 gallons of salable oil and tar per ton, which is too high. (See sec. 2.)

Detailed heat and material balances for a power plant using fluidized carbonization of lignite from Garrison damsite, N. Dak., as prepared by the Bureau of Mines, Denver, Colo., are presented in the following section.

Fluidized Processing of North Dakota Lignite for Power Production

Power requirements in the West are rapidly increasing, owing both to increasing population and substitution of electric power for other energy forms. Thermal power production will account for a large portion of this increase because of the limitations in potential hydroelectric development. Lignite, coal, natural gas, and residual fuel oils all compete for the thermal power market, and the selection of fuel will be determined by the cost of delivered energy and the costs incidental to their use.

The recent developments in utilization of Texas lignite for power production indicate that, in certain situations, processed lignite will be the most economical power-plant fuel. A plant is being erected in Texas using the process developed at the Denver laboratories of the Bureau of Mines. In this process, the raw lignite is crushed, dried in a stream of hot gases, and carbonized in a fluid-bed reactor to yield char, tar, and gas. The char will be used as power-plant fuel, a portion of the gas will supply the heat required to carbonize the coal, the remainder of the gas will supplement the char as boiler fuel, and the tar will be sold for chemical use.

The details of the pilot plants used to develop this process and the results of tests made are given in a recent publication of the Bureau (17). Lignite from Garrison Dam, N. Dak., was tested, and it was demonstrated that this lignite could be treated successfully in the pilot-plant units. The calculations in the present report are based on the use of Garrison lignite.

This report gives the results of study made to determine the probable heat and material flow rates for a 120,000-kw. thermal power plant operating on char obtained by the fluidized processing of Garrison damsite lignite. It deals only with the flow calculations required for the schematic design of the processing plant. Complete economic and engineering analyses of the application of processing must be made specifically for Garrison lignite and the power plant before further consideration of the plant.

Analysis of the proposed plant for the Texas installation indicated that the most economically sized processing unit would be one designed to serve units of 40,000-kw. generating capacity. It has been assumed in the present report that such units would also be most efficient for the Garrison application. On this basis, three integrated drying and carbonizing units would be required for a plant having 120,000-kw. generating capacity. Three units would permit operating the boiler on processed fuel over its entire operating range.

The annual fuel requirements of a 120,000-kw. plant operating at 90-percent plant factor on various fuels are shown in figure 11. This load would require 1,527,000 barrels of fuel oil a year or 9,461 million cubic feet of natural gas. If the plant were operated on char, 1,005,400 tons of lignite would have to be processed per year, producing 401,800 tons of char. In addition, processing this

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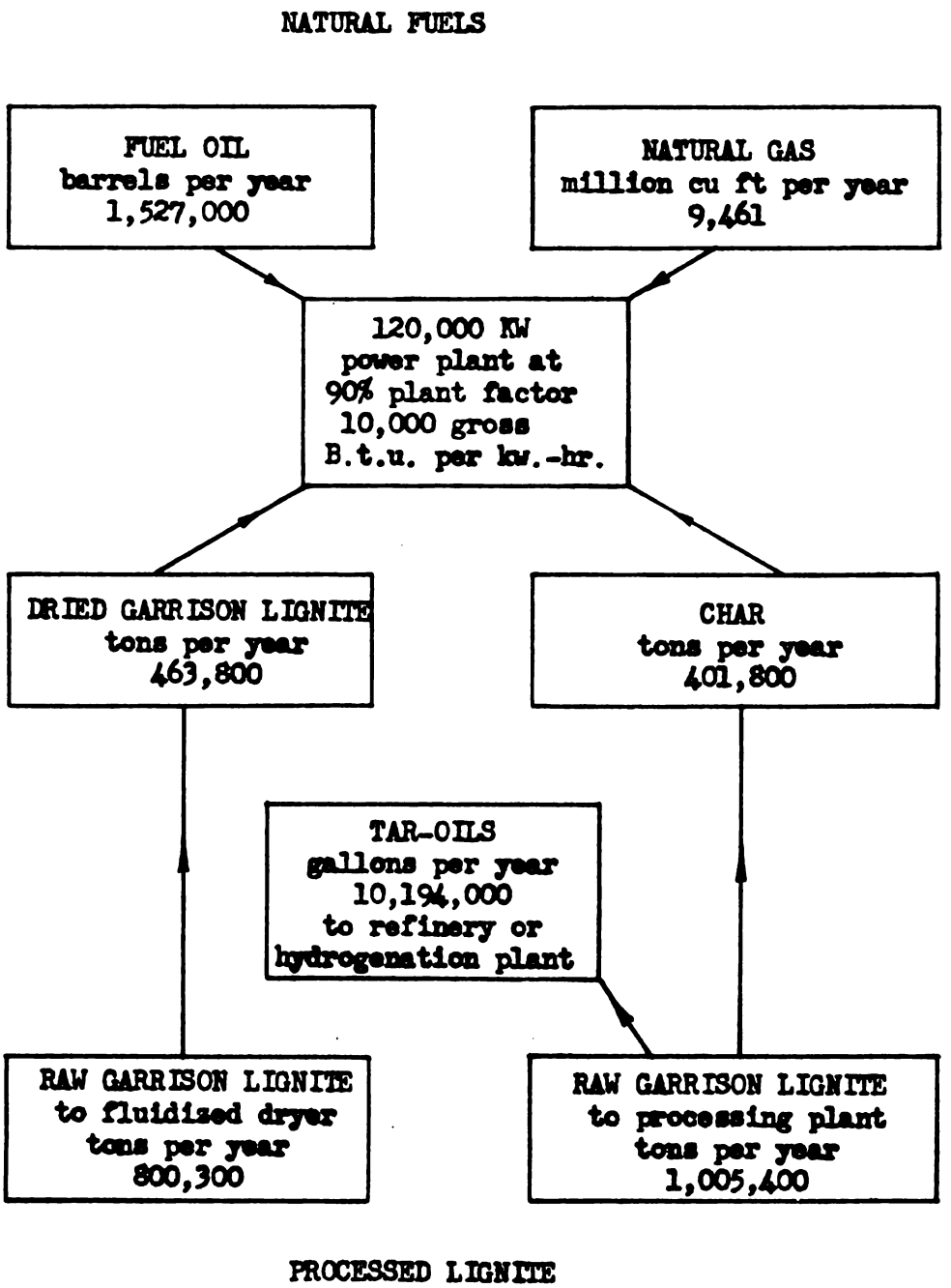

Figure 11. - Calculated fuel requirements for 120,000 kw. power plant.

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quantity of coal would produce 10,194,000 gallons of tar oils a year. The power plant could be operated by the combustion of 462,800 tons of dried lignite per year, requiring the drying of 800,300 tons of raw lignite. The difference in the raw lignite requirements for the two latter cases is due principally to the potential heat of the tar.

The overall flow of materials through the entire plant on an hourly basis is shown in table 8. For 120,000 kw., 225,060 pounds of raw lignite per hour must be processed, producing 101,940 pounds of char, 1,014 gallons of tar, 279 gallons of light oil, 335,000 std. c. f. of gas, and 2,241 gallons of liquor. The total gas make will be 607,000 cu. ft. per hr., but a portion of it is required to heat the carbonizer.

TABLE 8. - Overall heat and material flow rates for a 120,000-kw. generating plant, using Garrison damsite, N. Dak., lignite

(Hourly rates)

	Volume	Pounds	Gross potential heat, million B.t.u.	Net potential heat, million B.t.u.
Input:				
Raw lignite.....		225,060	1,644.0	1,473.9
Output:				
Char.....		101,940	1,200.0	1,170.9
Tar.....	1,014 gal.	8,910	151.2	143.1
Light oil.....	279 gal.	1,890	35.1	33.6
Process gas.....	335.1 M std.c.f.	27,600	36.3	32.7
Char in tar.....		180	2.1	2.1
Liquor.....	2,241 gal.	18,660		
		159,180	1,424.7	1,382.4

Table 10 shows the analysis of the net operation of the carbonizer. Each 40,000 kw. of generating capacity will require combustion of 33,980 pounds of this char per hour, which is the basic figure used in designing this plant. About 3,600 pounds of tar, including light oil, will be produced per hour from each unit, equivalent to 1,293 gallons per hour from the 3-unit plant.

The analyses of the raw, dried, and carbonized Garrison lignite are shown in table 11. The raw lignite, based on available analyses, is expected to contain 39.3 percent moisture and 6.9 percent ash and have a gross heating value of 6,450 B.t.u. per pound. The dried lignite will contain 3.9 percent moisture, 10.9 percent ash, and have a heating value of 10,200 B.t.u. per pound. The ash content of the char will be 16.2 percent, and its heating value will be 11,770 B.t.u. per pound.

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TABLE 9. - Overall drier heat and material balances for a combined drying and carbonizing unit operating on Garrison damsite, N. Dak., lignite and serving 40,000-kw. generating capacity1/

(Hourly basis)

	Temp., °F.	M std. c.f./hr.	Pounds	Net B.t.u. (thousands)
Input:				
Raw lignite	60		85,020	
Air	60	557.3	42,530	
Net heat liberated				42,300
		557.3	127,550	42,300
Output:				
Dried lignite	175		49,270	1,580
H_2O evaporated	275	656.6	31,290	36,170
Combustion gases	275	587.8	46,390	2,490
Ash out of furnace	1,600		330	150
Dust loss	175		270	10
Heat loss				1,900
		1,244.4	127,550	42,300

1/ 3 of these combined units are required for a 120,000-kw. generating plant.

TABLE 10. - Overall carbonizer heat and material balances for a combined drying and carbonizing unit operating on Garrison damsite, N. Dak., lignite and serving 40,000-kw. generating capacity1/

(Hourly basis)

	Temp., °F.	M std. c.f./hr.	Pounds	Net B.t.u. (thousands)
Input:				
Retort:				
Dried lignite	175		49,270	1,580
Air	700	147.8	11,280	1,780
Net heat liberated				14,690
Furnace:				
Air	1,200	106.8	8,150	2,350
Net heat liberated				8,880
		254.6	68,700	29,280
Output:				
Retort:				
Char	900		33,980	7,980
Tar	900	6.4	2,970	1,770
Light oil	900	2.2	630	370
Liquor	900	130.6	6,220	8,680
Process gas	900	111.7	9,200	2,140
Char in tar	900		60	20
Furnace:				
Stack gases	1,500	195.8	15,640	6,190
Heat loss				2,130
		446.7	68,700	29,280

1/ 3 of these combined units are required for a 120,000-kw. generating plant.

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TABLE 11. - Proximate analyses of raw, dried, and carbonized Garrison lignite

	Raw lignite	Dried lignite	Lignite char
Moisture.....percent	39.3	3.9	0
Volatile matter.....do.	26.4	41.8	19.7
Fixed carbon.....do.	27.4	43.4	64.1
Ash.....do.	6.9	10.9	16.2
Total.....	100.0	100.0	100.0
Gross B.t.u./lb.	6,450	10,200	11,770

Bibliography

1. BELL, C. H., AND ANDERSON, R. L. Production, Distribution and Use. Analyses of Michigan, North Dakota, South Dakota, and Texas Coals. Bureau of Mines Tech. Paper 700, 1948, 106 pp.

2. BURR, A. C., HENRICKSON, R., AND NATASILPA, S. Comparative Survey of Steam Power Plants Using North Dakota Lignite. Unpublished rept., North Dakota Research Foundation, 1951, 68 pp.

3. BUSINESS WEEK. Lignite Power Rouses North Dakota's Hopes. Apr. 19, 1952, pp. 166-171.

4. BLAINBRIDGE, J. L. Spreader Stokers Solution to Combustion Problems. Utilization, vol. 6, No. 11, 1952, pp. 33-36.

5. CRUISE, J. H., AND DELORENZI, O. Steam-Generating Unit Design for Burning Coals From the Northern Great Plains Province. Combustion Eng. Superheater, Inc., New York, 1951.

6. DELAURIER, D. W., AND HEIN, R. L. Neal Station Burns Pulverized Lignite. Power, vol. 97, No. 1, 1953, pp. 71-74, 208.

7. DRABELLE, J. M. Burning Low-Grade Midwestern Coals on Spreader Stokers With Continuous Ash Discharge. Trans. ASME, vol. 69, 1947, pp. 203-212.

8. _____. Lignite Properties and Application Data. Elec. World, Feb. 25, 1952, p. 104.

9. GILG, F. X. The Cyclone Furnace - Latest Thing in Coal Burning. Power Generation, vol. 54, No. 4, 1950, pp. 65-70.

10. GRUNERT, A. E., SKOG, L., AND WILCOXSON, L. S. The Horizontal Cyclone Burner. Trans. ASME, vol. 69, 1947, pp. 613-627.

11. HARDY, N. G. Operating Experience With Pulverized Texas Lignite in a Large Central Station. Trans. ASME, vol. 58, 1936, pp. 267-275.

12. HARGEST, W. J., AND MOLLER, R. A. Utilization of Lignite Coals. Ind. and Power, vol. 61, No. 6, 1951, pp. 87-100.

13. HOFFMAN, J. W., AND DRABELLE, J. M. Operation of Large Power Boilers With Lignite Coals. ASME Paper 51-F-18, 1951.

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14. KELLER, W. E. Verified Statement Before the Interstate Commerce Commission in the Matter of Increased Freight Rates, No. 243, 1951, 13 pp.

15. KREISINGER, H., AUGUSTINE, C. E., AND HARPSTER, W. C. Combustion Experiments With North Dakota Lignite. Bureau of Mines Tech. Paper 207, 1919, 44 pp.

16. MANUFACTURERS RECORD. Lignite to be Fuel at New Alcoa Plant in Texas. Vol. 120, October 1951, pp. 44-45.

17. PARRY, V. F., LANDERS, W. S., WAGNER, E. O., GOODMAN, J. B., AND LAMMERS, G. C. Drying and Carbonizing Fine Coal in Entrained and Fluidized State. Bureau of Mines Rept. of Investigations 4954, 1953, 43 pp.

18. PISTNER, L. Basic Elements of Design and Operation of Steam Generating Units for Utilization of North Dakota Lignites. ASME Paper 51-F-20, 1951.

19. RANDALL, D. T., AND KREISINGER, H. North Dakota Lignite as a Fuel for Power-Plant Boilers. Bureau of Mines Bull. 2, 1910, 42 pp.

20. SCHROEDER, H. C., AND STRASSER, R. J. Station Design With Cyclone-Fired Steam Generators. ASME Paper 51-A-118, 1951.

21. UTILIZATION. Electric Utilities and Coal. Vol. 5, No. 2, 1951, pp. 27-30.

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2. CARBONIZATION

Carbonization, destructive distillation, or pyrolysis is the heat treatment of organic substances in the absence of air to decompose the substances into a solid residue, liquid products, and gases. The temperature level applied during the process of carbonization influences greatly the yields and characteristics of the recovered products.

According to A. C. Fieldner (8):[1/]

> Low-temperature carbonization of coal may be defined as the heat treatment of coal in the absence of air at temperatures of 450° to 700° C. (842° to 1,292° F.) as distinguished from the usual high-temperature carbonization at temperatures of 900° to 1,200° C. (1,652° to 2,192° F). At 450° to 500° C. (842° to 1,292° F.) the tar yield is 2 to 3 times that of the ordinary high-temperature process for making coke or gas.

Table 12 shows approximate comparative yields obtained from low- and high-temperature carbonization processes.

TABLE 12. - Approximate comparative yields of high- and low-temperature carbonization processes [1/] [2/]

	Low-temperature carbonization		High-temperature carbonization byproduct coke oven
	Externally heated retort	Internally heated retort	
Coke.....percent	70 - 80	60 - 75	60 - 70
Volatile matter in coke.....,percent	7 - 15	7 - 15	1 - 2
Gas.....cu. ft./ton	3,000 - 5,000	20,000 - 50,000	11,000 - 12,000
Heating value of gas.....B.t.u./cu. ft.	800 - 1,000	150 - 250	520 - 580
Tar..... gal./ton	20 - 30	18 - 20	10 - 12
Specific gravity of tar..	1.07 - 1.09	1.02 - 1.07	1.19
Light oil.....gal./ton	2.5 - 3.0	None	2.5 - 3.0
Ammonium sulfate..lb./ton	10 - 12	12 - 18	25 - 30

1/ Fieldner, A. C., Low-Temperature Carbonization of Coal: Bureau of Mines Tech. Paper 396, 1926, p. 43.
2/ Data apply to the carbonization of coal and not to lignite.

The yield of coke is higher for low-temperature carbonization processes because it retains 7 to 15 percent of volatile matter, as compared with 1 to 2 percent in high-temperature coke. Volume of gas is only one-fourth to one-third that obtained in high-temperature coking, but the heating value is almost twice that of gas from high-temperature carbonization when externally heated retorts are used. Low-temperature-carbonization processes internally heated by products of combustion produce large quantities of gas of low heating value. The total yield of tar at low temperatures is from 2 to 3 times that obtained at high temperatures. The quantity of light oil is about the same for both processes. However, the concentration of light-oil vapors in gases obtained by internal heating is too low for efficient recovery.

1/ Underlined numbers in parentheses refer to citations in the bibliography at the end of this section.

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Although these data apply to the carbonization of higher rank coal, yields obtainable from carbonization of lignite show the same general trend as a function of the processing temperature. Unlike the bituminous coals that form a coherent coke upon heat treatment, lignite and subbituminous coal do not become plastic and therefore produce a residue or char, consisting of nonagglomerated particles smaller than the material charged.

Results of Assay Tests on North Dakota and Other Selected Lignites

Preliminary evaluation of the economic promise of low-temperature carbonization of a given coal or lignite is primarily based on the results of laboratory investigations, which supply information on yields of tar, coke, and gas. Laboratory-scale carbonization in properly designed assay apparatus has been shown to indicate the approximate maximum tar yields to be obtained at a given carbonization temperature. Variation of yield as a function of processing temperature is also readily determined. Comparison of yields obtained in commercial plants with those from assay tests is helpful in determining optimum operating conditions and evaluating various processing methods. The Franz Fischer assay apparatus developed in Germany has been widely used in carbonization assay investigations. The method, which uses 250 grams of coal, is described by Davis and Galloway (7), who assayed numerous coals by this technique.

V. F. Parry and coworkers refined the Fischer method (13) for use with low-rank coals; the apparatus is shown in figure 12. From 150 to 200 grams of coal is used for a test. A carbonization temperature of 500° C. was adopted as a standard, whereas in the Fischer method 550° C. was originally employed. Because of the modifications used, results of the assay tests with the original and modified methods are not strictly comparable. However, yields of tar and light oil differ by not more than approximately 0.2 percent. Gas yield is slightly higher and coke yield lower at the higher temperature. The influence of changes on assaying temperature on yields from Sandow lignite is shown in figure 13. Results of assay tests on lignites made by the Fischer method have been reported by J. D. Davis and A. E. Galloway (7); H. F. Yancey, K. A. Johnson, and W. A. Selvig (31); W. A. Selvig (29); and W. H. Ode and W. A. Selvig (21).

Results of tests made on North Dakota lignites are reported in table 13. To eliminate difference in moisture and ash content of the various lignites, yields were calculated to moisture- and ash-free basis, unless MAF data were already available in the original publications. Average yields and range of yields for North Dakota lignites calculated from data of table 13 are given in table 14.

The rather wide variation of tar yields, ranging from 5.0 to 9.4 percent for all tests listed in table 13, should be noted. Lignites from Divide, Williams, Burleigh, Morton, Stark, and Grant Counties had higher tar yields than those obtained from Burke, Ward, and Mercer Counties. Although results of a number of assay tests run on North Dakota lignites are available, lignites from some areas of the State have not as yet been assayed.

Additional results of assay tests on other United States lignites are given in table 15. Only one lignite from South Dakota was tested. The yield of tar and light oil from this lignite was 5.8 percent. Lignites from Arkansas had yields of tar and light oil as high as 20 percent calculated to the moisture- and ash-free basis. Primarily this results from a different petrographic composition, as pointed out by Selvig (29).

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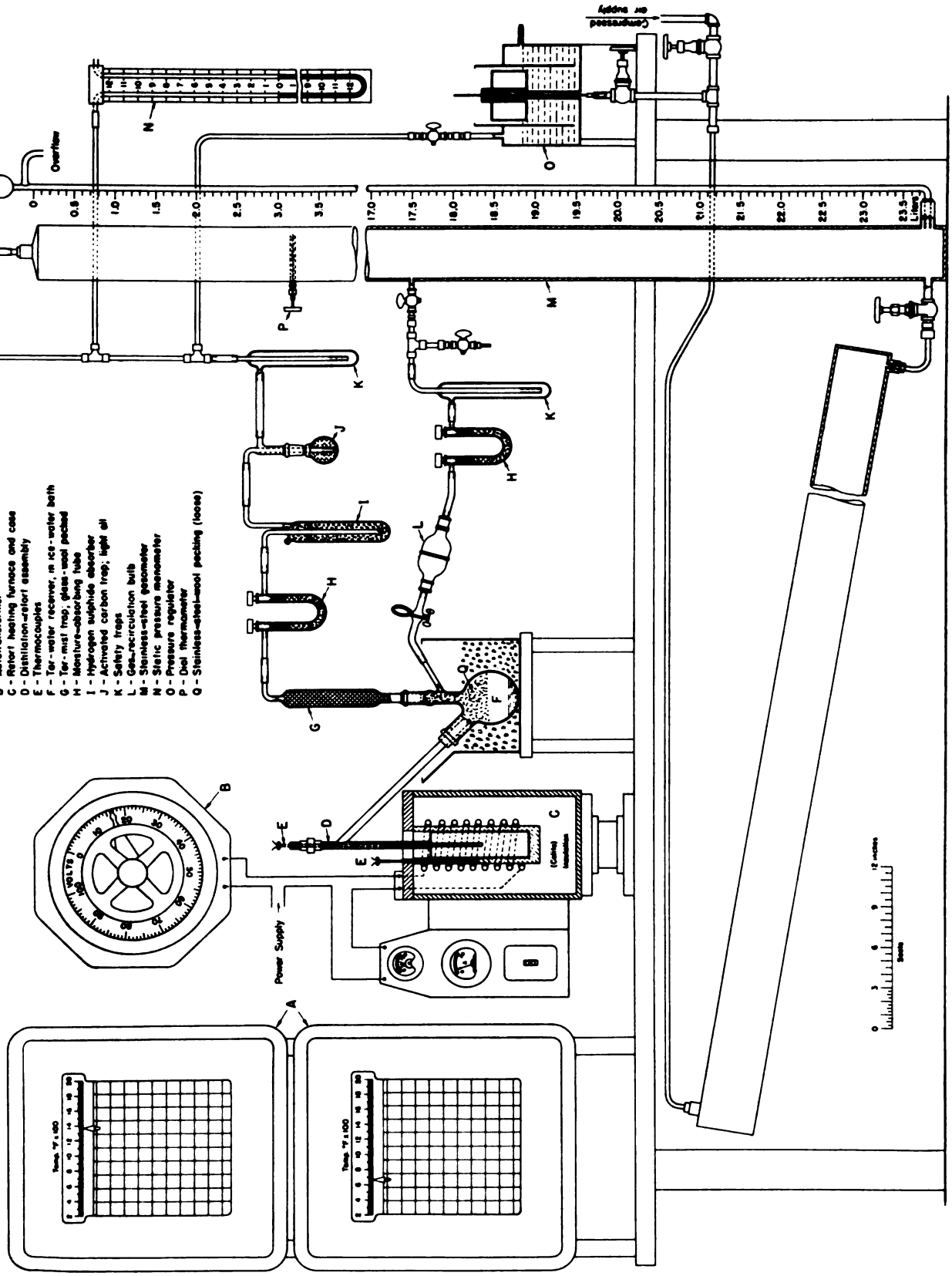
LEGEND
A - Temperature recorders
B - Autotransformer
C - Retort heating furnace and case
D - Distillation-retort assembly
E - Thermocouples
F - Tar - water receiver, in ice - water bath
G - Tar-mist trap, glass-wool packed
H - Moisture-absorbing tube
I - Hydrogen sulphide absorber
J - Activated carbon trap, light oil
K - Safety traps
L - Gas recirculation bulb
M - Stainless-steel gasometer
N - Static pressure manometer
O - Pressure regulator
P - Dial thermometer
Q - Stainless-steel-wool packing (loose)
Overflow
Compressed air supply
Power Supply
VOLTS
Liters
Inches

Figure 12. - Modified distillation assay apparatus.

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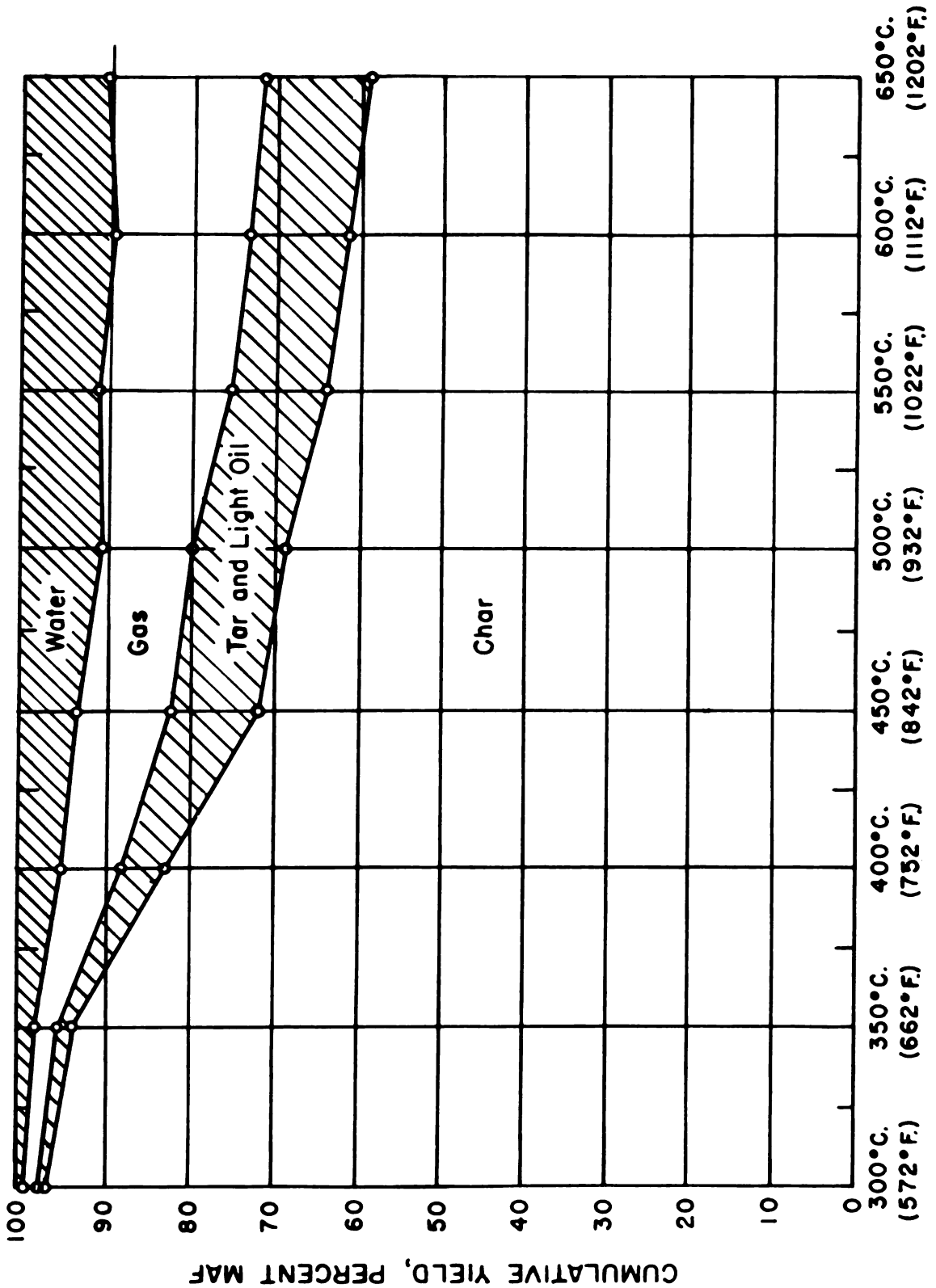

Figure 13. - Low-temperature carbonization yields in laboratory precision assay from Sandow lignite (sample 482).

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TABLE 13.—Results of assay carbonization tests on North Dakota lignites by the Fischer method

State County Mine name	1/ N. Dak. Divide Baukol- Noonan Noonan	2/ N. Dak. Divide Baukol- Noonan Noonan	3/ N. Dak. Burke Truax Columbus	3/ N. Dak. Williams Reclamation Williston	4/ N. Dak. Ward Velva Velva	1/ N. Dak. Ward Velva Velva	2/ N. Dak. Ward Velva Velva	3/ N. Dak. Mercer Pratt Corp. Zap	4/ N. Dak. Mercer Beulah Beulah	1/ N. Dak. Mercer Beulah Beulah	2/ N. Dak. Mercer Beulah Beulah	3/ N. Dak. Burleigh Wilton Wilton	4/ N. Dak. Burleigh Wilton Wilton	3/ N. Dak. Stark Pittsburgh Dickinson	1/ N. Dak. Stark Dickinson	4/ N. Dak. Morton New Salem New Salem	3/ N. Dak. Grant Knapp New Leipsig
Moisture, as recd., %			32.2	36.1	35.4			33.6	35.6			39.7	40.9	42.6		37.1	34.1
Ash, as recd., %			8.5	9.9	5.0			6.2	5.7			6.0	5.5	5.7		7.0	10.1
Temp. of distill., °C.	500	500	550	550	550	500	500	550	550	500	500	550	550	550	500	550	550
Assay yields, MAF, %:																	
Char				59.1	60.8			64.4	62.7				62.3			60.0	
Water				13.9	14.3			10.3	12.6				11.6			12.3	
Tar + light oil	8.8	9.4	5.7	8.3	7.2	5.0	5.4	6.0	6.1	5.4	5.9	6.3	8.6	8.3	6.9	8.2	9.0
Gas			17.9	18.7	17.1			19.3	18.1			21.2	18.3	22.4		16.6	21.7
Hydrogen sulfide			-	-	-			-	-			-	-	-		-	
Gas composition, %:																	
Carbon dioxide			46.7	48.3	41.5			47.2	45.6			50.3	43.9	53.0		43.3	48.1
Illuminants			1.8	1.8	2.4			1.6	3.0			1.4	2.8	1.6		2.2	2.1
Carbon monoxide			9.1	8.5	12.1			10.1	10.0			11.7	10.5	9.3		9.8	8.7
Hydrogen			17.6	17.5	13.9			15.2	13.6			14.8	14.3	11.6		15.5	15.6
Methane			19.3	19.2	24.9			21.7	24.3			16.9	23.9	18.9		23.6	20.1
Ethane			5.5	4.7	5.2			4.2	3.5			4.9	4.6	5.6		5.6	5.4
B.t.u./cu.ft. calc., gross			408	389	466			401	430			364	447	383		454	412
Net gas, cu.ft./lb., MAF			2.405	2.320	2.355			2.660	2.385			2.800	2.370	2.860		2.500	2.615
Net gas, cu.ft./ton, MAF			4810	4640	4710			5320	4770			5600	4740	5720		5000	5230
Heat in gas, B.t.u./lb., MAF			981	902	1098			1066	1025			1019	1060	1095		1135	1078
Tar, gal./ton, as recd.			8.2	9.5	10.4			8.6	8.6			8.1	11.1	10.3		11.2	12.1

1/ Selvig, W. A., Properties of Lignites of the United States: Fuel, vol. 32, No. 1, January 1953, pp. 28-35.

2/ Ode, W. G., and Selvig, W. A., Low-Temperature Distillation Yields of Primary Tar and Light Oil from Coals of Various Ranks and Types: Bureau of Mines Rept. of Investigations 3748, 1944, 10 pp.

3/ Davis, J. D., and Galloway, A. E., Low-Temperature Carbonization of Lignites and Sub-Bituminous Coals: Ind. Eng. Chem., vol. 20, No. 6, 1928, pp. 612-17.

4/ Yancey, H. F., Johnson, K. A., and Selvig, W. A., Friability, Slacking Characteristics, Low Temperature Carbonization Assay and Agglutinating Value of Washington and Other Coals: Bureau of Mines Tech. Paper 512, 1932, 94 pp.

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TABLE 14. - Assay-carbonization yields of North Dakota lignites by Fischer-assay method

Assay yields, MAF, percent[1]	Average	Range
Char	61.6	59.1 - 64.4
Water	12.5	10.3 - 14.3
Tar + light oil	7.4	6.0 - 8.6
Gas	18.4	17.1 - 19.3
Gas data:		
B.t.u./cu.ft. calc. gross	431	389 - 466
Net gas, cu. ft./ton, MAF	4,863	4,640 - 5,320
Heat in gas B.t.u./lb., MAF	1,048	902 - 1,135
Tar + light oil gal./ton lignite as mined	9.9	8.6 - 11.2

1/ Only complete tests used for this calculation.

TABLE 15. - Results of assay tests on other United States lignites by Fischer-assay method

State	1/ South Dakota	2/ Arkansas	2/ Arkansas	3/ Washington
County	Harding Ellis Gobert	Ouachita	Ouachita	Lewis Prospect
Moisture, as recd. percent	41.0			
Ash, as recd do.	7.4			
Temperature of distill °C.	550	500	500	500
Assay yields, MAF, percent:				
Char	73.2			
Water	1.4			
Tar + light oil	5.8	19.8	20.5	10.7
Gas	20.5			
Hydrogen sulfide	-			
Gas composition, percent:				
Carbon dioxide	55.3			
Illiminants	1.6			
Carbon monoxide	7.0			
Hydrogen	16.1			
Methane	15.4			
Ethane	4.6			
B.t.u./cu.ft., calc., gross	337			
Net gas, cu.ft./lb. MAF	2.570			
Net gas, cu.ft./ton MAF	5,140			
Heat in gas, B.t.u./lb. MAF	866			
Tar, gal./ton as recd.	7.2			

1/ Davis, J. D., and Galloway, A. E., Low-Temperature Carbonization of Lignites and Subbituminous Coals: Ind. Eng. Chem., vol. 20, No. 6, 1928, pp. 612-17.

2/ Selvig, W. A., Properties of Lignites of the United States: Fuel, vol. 32, No. 1, January 1953, pp. 28-35.

3/ Ode, W. H., and Selvig, W. A., Low-Temperature Distillation Yields of Primary Tar and Light Oil From Coals of Various Ranks and Types: Bureau of Mines Rept. of Investigations 3748, 1944, 10 pp.

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Attrital lignites, like the Arkansas lignites, which contain more or less debris of leaves, bark, spores, pollen, and resins, yield more tar than woody lignites, which predominate in North Dakota.

V. F. Parry and coworkers have tested numerous coals and lignites in the modified distillation-assay apparatus and reported the results in various publications (12, 23, 24), from which complete data on North Dakota lignites and selected data on Texas lignites are presented in tables 16 and 17. Among the Texas lignites, only the Sandow lignite is significant in extent of deposits.

Average yields and range for both North Dakota and Texas lignites are shown in table 18.

Yields of products from low-temperature carbonization of North Dakota lignites, recalculated to as-mined basis and expressed in English units of measure per ton of lignite carbonized, are given in table 19.

On the average, approximately 82 percent of the potential heat of the lignite was recovered in the char, about 10 percent in the tar and light oil, and 6 to 8 percent in the gas.

An extensive series of determinations of carbonizing properties of coking coals has been carried out by the Bureau of Mines in cooperation with the American Gas Association. In the BM-AGA test (26), 13- or 18-inch-wide retorts containing charges of 75 to 180 pounds of coal are used, in comparison to the 150 to 250 grams employed in the assay tests previously described. This procedure and apparatus have been used to investigate the carbonizing properties of a single North Dakota lignite, Velva lignite from Ward County, at temperatures ranging from 500° to 900° C. (932° to 1,652° F.) (27).

At 500° C. approximately half of the yield of tar and light oil indicated by Fischer assay was obtained in the BM-AGA test. The reduced yield is the consequence of longer residence time of the charge in the BM-AGA test, coupled with a considerable temperature gradient across the retort which promotes cracking of tar vapors at the wall and in the hotter section of the charge.

Lignites shrink considerably during the process of carbonization as a result of the large amounts of water vapor and gas released during decomposition of the coal substance.

The contraction of volume of Velva lignite as a function of test temperature is shown in table 20, as determined in the BM-AGA test.

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TABLE 16. - Results of assay tests on North Dakota lignites by modified distillation-assay apparatus

Mine name	Baukol-Noonan	Baukol-Noonan	Kincaid	Custer	Garrison	Garrison	Garrison	Garrison	Beulah	Zap	Dickinson
County	Divide	Divide	Burke	McLean	McLean	McLean	McLean	McLean	Mercer	Mercer	Stark
Moisture, as recd. .....percent	35.2	36.6	34.0	39.0	39.9	39.9	38.8	38.8	36.0	33.7	38.1
Ash, as recd. .... do.	5.2	6.9	6.2	4.4	6.3	6.3	7.6	7.6	9.0	6.3	7.7
Temp. of distillation, °C.	500	500	500	500	500	450	500	450	500	500	500
Assay yields, MAF, percent:											
Char	69.3	67.6	68.2	67.3	69.3	72.2	68.2	73.5	68.7	67.9	66.3
Water	10.0	10.5	11.1	9.6	11.2	8.6	9.3	8.5	9.6	10.6	13.0
Tar	5.5	5.4	4.2	5.6	6.6	7.3	8.0	6.6	4.3	4.9	3.9
Light oil	1.6	1.4	1.4	1.5	1.6	1.6	1.4	1.4	1.6	1.3	1.2
Tar + light oil	7.1	6.8	5.6	7.1	8.2	8.9	9.4	8.0	5.9	6.2	5.1
Gas	13.4	15.1	15.0	15.8	11.0	10.6	13.1	10.3	15.2	15.0	14.9
Hydrogen sulfide	0.4	0.3	0.3	0.4	-	-	-	-	.6	.5	.9
Gas composition, percent:											
Carbon dioxide	49.5	54.3	52.2	51.1	36.2	55.8	44.4	61.9	56.4	49.8	54.3
Illuminants	0.7	0.7	0.5	0.5	1.3	1.5	1.0	0.9	.7	.8	.5
Carbon monoxide	13.9	11.3	13.0	14.5	11.4	12.3	11.4	13.5	11.0	12.9	11.4
Hydrogen	9.7	11.4	9.8	9.6	16.2	5.0	13.9	4.8	10.1	10.3	9.9
Methane	24.3	21.2	23.2	23.2	28.7	22.1	29.3	18.6	20.4	25.5	22.8
Ethane	1.9	1.1	1.3	1.1	6.2	3.3	0.0	0.3	1.4	.7	1.1
B.t.u./cu.ft. .....calc. gross	366	318	337	338	511	366	394	268	310	358	325
Net gas .....cu.ft./lb. MAF	1.657	1.825	1.828	1.920	1.583	1.192	1.746	1.130	1.788	1.860	1.795
Heat in gas .....B.t.u./lb. MAF	607	580	617	650	809	436	688	303	555	666	584

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TABLE 17. - Results of assay tests on Texas lignites by modified distillation-assay apparatus

Mine name	Malakoff	Sandow	Sandow[1]	Freestone
County	Henderson	Milam	Milam	Freestone
Moisture, as recd. .....percent	36.3	35.2	35.6	36.2
Ash, as recd. ..... do.	8.0	8.4	7.9	8.1
Temp. of distillation..... °C.	500	500	500	500
Assay yields, MAF, percent:				
Char.....	64.9	66.1	68.0	64.2
Water.....	7.6	8.6	7.3	8.0
Tar.....	14.7	11.5	10.9	14.6
Light oil.....	1.8	2.0	1.8	1.8
Tar + light oil.....	16.5	13.5	12.7	16.4
Gas.....	10.9	12.3	12.1	11.1
Gas composition, percent:				
Carbon dioxide.....	42.5	42.4	41.7	36.2
Illuminants.....	1.6	1.8	1.9	1.8
Carbon monoxide.....	8.9	9.8	11.7	9.8
Hydrogen.....	15.8	6.2	11.8	15.6
Methane.....	26.4	38.1	30.0	34.6
Ethane.....	4.8	1.7	2.9	2.0
B.t.u./cu. ft. .....calc. gross	460	499	465	500
Net gas.....cu. ft./lb. MAF	1.474	1.400	1.608	1.627
Heat in gas.....B.t.u./lb. MAF	678	697	749	814

1/ Average of 4 tests on same sample.

TABLE 18. - Comparative assay yields of North Dakota and Texas lignites, assay temperature 500° C. (932°F.)

	North Dakota		Texas	
	Average	Range	Average	Range
Assay yields, MAF, percent:				
Char.....	68.1	66.3 - 69.3	65.8	64.2 - 68.0
Water.....	10.5	9.3 - 13.0	7.0	7.3 - 8.6
Tar.....	5.4	3.9 - 8.0	12.9	10.9 - 14.7
Light oil.....	1.4	1.2 - 1.6	1.9	1.8 - 2.0
Gas.....	14.3	11.0 - 15.8	11.6	10.9 - 12.3
Gas data:				
B.t.u./cu.ft.....calc. gross	362	310 - 511	481	460 - 500
Net gas.....cu.ft./lb. MAF	1.778	1.583-1.860	1.527	1.400-1.627
Heat in gas..... B.t.u./lb. MAF	640	555 - 809	735	678 - 814

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TABLE 19. - Yields of products of low-temperature carbonization of North Dakota lignite

Mine name	Baukol-Noonan	Kincaid	Custer	Garrison	Beulah	Zap	Dickinson	
County	Divide	Burke	McLean	McLean	Mercer	Mercer	Stark	Average
Moisture in coal as mined.....percent	36.6	34.0	39.0	39.9	36.0	33.7	38.1	36.8
Ash in coal as mined.....percent	6.9	6.2	4.4	6.3	9.0	6.3	7.7	6.7
Yields, per ton of coal, as mined:								
Char.....lb.	902	940	850	871	936	941	873	902
Tar.....gal.	7.4	6.0	7.6	8.5	5.7	7.1	5.1	6.8
Light oil....do.	2.4	2.6	2.6	2.6	2.7	2.4	2.2	2.5
Gas.....cu. ft.	2,062	2,187	2,173	1,703	2,010	2,230	1,954	2,046
Water.....lb.	845	813	890	919	826	794	902	856
Gas.... B.t.u./lb. of lignite	328	369	368	435	305	400	316	360
Char.....B.t.u./lb.	12,330	12,610	12,970	12,470	11,770	12,580	12,060	12,400
Potential heat of lignite recovered in char.....percent	80.1	82.0	81.4	84.2	83.3	81.8	80.7	81.9
Volatile matter in char.....percent	17.8	18.0	18.6	18.6	19.0	18.8	19.2	18.6
Ash in char... do.	13.9	11.5	9.1	12.4	17.6	13.0	15.5	13.3

TABLE 20. - Contraction in volume of charges of Velva lignite as mined in BM-AGA tests as a function of processing temperature

Test temperature, °C.	Contraction, percent by volume
500	33.1
600	47.3
700	47.5
800	51.5

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Process Methods

Experimental carbonization of lignite has been carried out in this country since the middle of the last century. Objectives of lignite carbonization have changed from time to time as a result of contemplated end uses for the products. Before development of convenient oil-burning equipment and construction of numerous power plants, almost all of the lignite mined in the North Central region was used for domestic heating. The main objective of lignite carbonization under these circumstances was to provide a smokeless, agglomerated fuel from the resultant char. Recovery of tar and oils was considered of secondary importance. When coal gas was rather extensively used for municipal distribution in North Dakota, gas coals for manufacturing the gas had to be imported. It was therefore proposed to use lignite in the conventional retorts of gas plants for manufacture of city gas. Because gas was the desired end product, carbonization temperatures had to be very high, which resulted in low tar yields. Meanwhile, oil and natural gas have increasingly replaced solid fuels for domestic heating, and electricity and petroleum gases are predominantly used for cooking and hot-water service. The more recent concept of the end uses for products of carbonization of lignite are utilization of the char as fuel for power generation and utilization of the tar as a source for chemicals. In this case, the char must compete with nonprocessed lignite, natural gas, and heavy fuel oils, and revenue from tar must absorb the cost of the carbonization process. Therefore, the potential tar content of the lignite should be high, recovery of the tar should be as complete as possible, and the carbonization process should be cheap.

Pilot and Commercial Plants for Carbonizing American Lignites

Glenk (11) has reported that Arkansas lignite was carbonized as early as 1859 by Robert Peter to produce gas for generating heat and power. A very crude process to carbonize Arkansas lignite was operated in 1885. The resultant char was pulverized and mixed with the oils and other ingredients and the mixture sold as rough black paint, which was used principally on iron and steel.

In the summer of 1900, the Laclede Gas Light Co. of St. Louis, Mo., installed an experimental bench of 4 horizontal D-shaped fire-clay retorts in which 20 carloads of Arkansas lignite were carbonized. As a result of high carbon dioxide content of the gas, which was too high to be removed economically, it was concluded that lignite gas could not be used as illuminating gas (6).

Later, Darling (6) designed an inclined slowly rotating cylindrical iron retort, which was placed in a combustion chamber. The process proved satisfactory with respect to yields, but the iron retort deteriorated rapidly under the high temperature.

E. J. Babcock, of the University of North Dakota, and his coworkers took a leading part in early work on development of North Dakota lignite. Extensive investigations were made on carbonization of lignite and briquetting of residual char. An experiment station was established at Hebron, N. Dak., where experiments were carried out on a large pilot-plant scale.

Babcock (1) and Babcock and Odell (2) reported in detail on types of carbonizing equipment and presented operating data. Hood and Odell (15) reviewed development of the technique of lignite carbonization up to that time.

Although the Bureau of Mines since its establishment had taken an active interest in utilization of lignite and development of the lignite deposits of the United States, Congress, by an act of February 25, 1919, authorized the Secretary of the Interior to make investigations, through the Bureau of Mines, of lignites and peat to determine the

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practicability of utilization as fuel and in producing commercial products. As a result of this authorization, a cooperative agreement between the Bureau of Mines and the University of North Dakota was signed in 1922 covering the joint use of a lignite carbonizing oven and accessories. Results of runs made in this oven were reported by Odell (22).

Externally heated cast-iron or clay retorts first used were operated at fairly high temperatures, ranging from 1,200° to 1,800° F., with the maximum quantity and quality of gas obtained at 1,200° to 1,400° F. The clay retort was capable of carbonizing about 400 pounds of lignite in 4 hours. Lignites from North Dakota, Montana, Colorado, and Texas were tested. Average figures resulting from 25 experiments run on air-dried lignite containing 8 to 27 percent moisture were reported as follows:

Operating temperature, 1,110° - 1,700° F.

Gas yield	11,038	cu. ft. per ton of air-dried lignite
Heating value of gas	396	B.t.u. per cu. ft.
Char yield	54.6	percent of the original charge of air-dried lignite
Heating value of char	11,838	B.t.u. per pound

After further preliminary experiments, a large, externally heated, inclined retort having a capacity of about 20 tons of lignite per day and consisting of 6 double retorts with 18 gas offtakes arranged to remove gas at 3 separate levels, was constructed and operated. Tops of the retorts were not closed, a feed hopper of lignite acting as a seal. A single retort was 16 feet long, 30 inches wide, and 10 inches high. Gas and byproducts could be collected, and stripped gas could be returned to the fire box. The influence of temperature, size of lignite, and time of carbonization on quality and quantity of products was investigated. Yields of tar were small because some tar was carbonized in the fuel mass. The char obtained was satisfactory for briquetting. A typical material balance for a ton of lignite, calculated from data for a test run of 1 week, is given in table 21.

TABLE 21. - Material balance for carbonization of lignite in inclined retort

		Pounds	Percent
Input:	Lignite, as mined (moisture 28.2%)	2,000	100
Recovered:	Char	807	40.4
	Water, calc. from lignite analysis	564	28.2
	Gas	302	15.1
	Tar	19	0.9
Total accounted for		1,692	84.6
Unaccounted for and losses		308	15.4

Losses include water-soluble products, leakage, combustion of gases and tar leaking into the flues, and water formed on distillation of the lignite.

In an attempt to obtain increased capacity and lower processing cost, an internally heated oven of relatively simple design was built. This oven consisted essentially of a vertical shaft 6 feet high inside and 3 by 3 feet wide. A device

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to cool and quench the char was attached to the carbonizing shaft. To supply heat for carbonization, a combustion zone was maintained at the middle of the oven by supplying air through airports opening into the combustion zone, burning a portion of the lignite charge. No provision was made to collect gases and tar evolved during the carbonization process. The oven carbonized 16 tons of as-mined lignite a day, producing 6.4 tons of char suitable for briquetting.

Lurgi-Spülgas Process

The concept of using lignite char as a source for storable, high-B.t.u. briquets led in 1928 to construction of two commercial plants on the North American continent, one at Dickinson, N. Dak., and the other at Bienfait, Saskatchewan, Canada. These two plants use the Lurgi-Spülgas internally heated carbonization process developed in Germany in the early 1920's (3, 17).

The basic principles of the Lurgi process are the following:

1. Any noncoking fuel, crushed and screened to suitable size can be used without pretreatment.

2. Tar can be recovered with high yield, without excessive cracking, and without dust.

3. The charge is slowly dried at controlled temperatures before the actual carbonization process.

4. The zones of drying and carbonizing of the coal and cooling of the char are clearly separated.

5. The whole three-step process is entirely continuous.

Figure 14 shows a diagram of the Lurgi carbonizer.

The North Dakota plant at Dickinson, formerly known as the Lehigh Briquetting Co. and now operated by the Dakota & Tar Products, Inc., has been described by R. Dawson Hall (14).

In this plant lignite as mined is crushed to 4-inch or less, and the crushed material is passed over a vibrating screen. Undersize, consisting of approximately minus-1/4-inch particles, goes to the power plant, and oversize is charged to the carbonizer.

In the upper section of the retort, moisture is removed from the lignite, and in the lower section carbonization takes place. Part of the gas originating from carbonization and having a heating value of about 190 B.t.u. per cubic foot is mixed with air and burned outside the drier, and the products of combustion are recirculated through the drying zone. Moisture is removed from the lignite during its passage through the drier and is vented to the atmosphere. Considerable disintegration takes place during the drying process, leaving a dried product of approximately 3/4 inch maximum size, which descends through 8 pipes into the carbonization section, which is operated on the same principle as the drier and is equipped with ducts for distributing the hot products of (external) combustion from the recycle gas. The gas mixture enters at 1,300° F. and heats the lignite to approximately 1,100° F., decomposing it to char, gas, and tar vapors. Char residue goes to the bottom of the carbonizer, where it is cooled by carbonization gas, as recycled. A gas mixture consisting of carbonization gas, tar vapors, and inert products of combustion is drawn off at the

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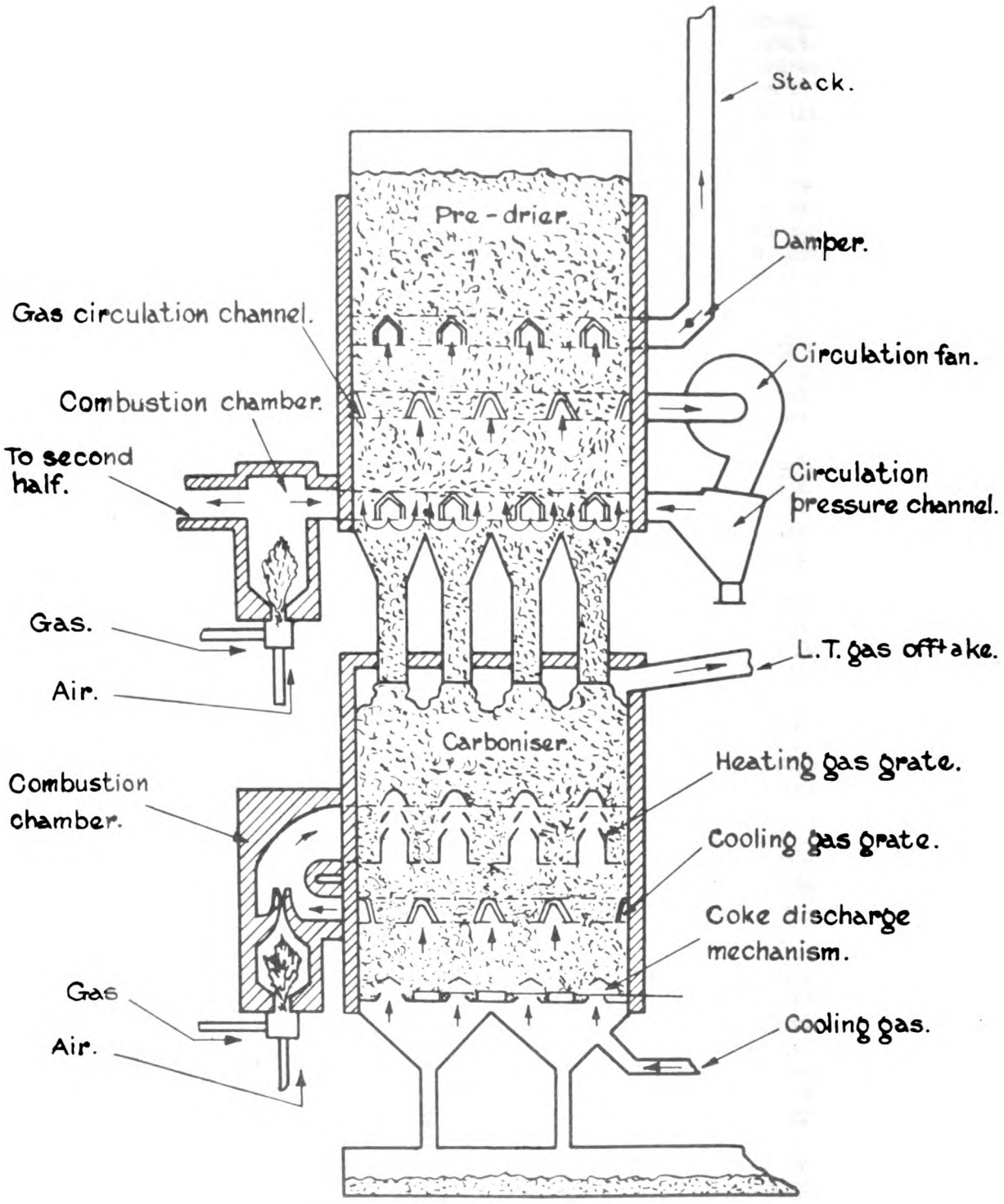

Figure 14. - Diagram of Lurgi carbonizer.

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top of the carbonization chamber at approximately 350° F. Char is discharged at the bottom at about 200° F. Total height of the carbonizer installed at Dickinson is approximately 85 feet, and the drying and carbonization sections are each 20 feet long and 6 feet wide.

Gas leaving the carbonization section is washed in a water-spray scrubber to take out dust, tar is removed by an electrostatic precipitator, and final cooling is accomplished in two scrubbers filled with grids. Clean gas is returned to the carbonizer to cool the char and supply the heat requirement for drying and carbonization.

There are two Lurgi carbonizers installed at the Dickinson plant, each having a daily capacity of approximately 100 to 150 tons of lignite as mined.

At Dickinson the tar and oils, after separation from water condensate, are distilled into a liquid fraction and a pitch residue. The distillate oil is sold for use as a wood preservative, and the pitch serves as part of the binder for manufacturing briquets from the char. Pitch obtained is not sufficient to meet requirements for briquetting and must be supplemented by petroleum asphalt.

Approximately 5 gallons of tar and oils per ton of as-mined lignite were recovered during actual operation of the plant, or about 70 percent of the yield, as determined in the laboratory. Tar and oil recovery is influenced in part by the fact that facilities are not available for stripping the light oil from the gas after the tar-recovery system. It has been reported (3) that 83 percent of the assay yield was recovered in a newer Lurgi-Spülgas plant, which scrubbed light oil from the gas, whereas the yield was 71 percent of assay disregarding the recovered light oil.

Economic success of the Dickinson plant did not come up to expectation because its main value product is briquets for the domestic market, which has been declining because of competition from other fuels. Quality of the char briquets, having a heating value of about 12,000 B.t.u. per pound, is very satisfactory as far as burning properties and storability are concerned. Tar production is not sufficient in quantity to process it for maximum realization.

Fluidized Carbonization, Bureau of Mines, Denver, Colo.

Work on low-temperature carbonization of lignite, using new techniques, has recently been successfully reactivated by V. F. Parry of the Denver laboratories of the Bureau of Mines. The Texas Power & Light Co. cooperated with the Bureau of Mines in this development work. In this process, carbonization of fine-particle coal in the fluidized state is used to obtain high heat-transfer rates, high capacities, and low operating costs (4, 5, 20, 24). Feed size of the coal is minus-1/4-inch. Required residence time of the particles in the carbonizer is 10 to 15 minutes.

The process developed by Parry consists of two steps. Lignite, as-mined, is crushed to minus-1/4-inch and dried in the entrained state in a stream of hot gases. This process has been described in section 5 part 1. The dried coal is then transferred to the fluidized carbonization retort. In the carbonization retort, process heat is furnished in part by combustion within the retort through limited addition of air and in part by external heating. The mixture of char, gases, and tar vapors leaving the retort at the top is separated in conventional dust-removal equipment and a specially designed hot electrostatic precipitator. Nonagglomerating coals can be carbonized readily in the entrained and fluidized state by this technique.

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Because operating data are not available from the commercial plant now under construction, the equipment used during development will be described. The 300-pound-per-hour pilot plant, which was used to develop the technique of fluidized carbonization and to determine yields, is shown in figures 15 and 16. It consists of an 8-inch steel retort having a sprayed coating of 312 alloy to prevent oxidation. The retort is suspended within a refractory-lined outer chamber heated with gases produced by combustion of natural gas and air in an external furnace. Coal is fed by a mechanical vane feeder from the dried-coal hopper into a stream of air or recirculated process gas that transports the dried coal to the fluidized-carbonization retort. With a gas velocity of 3 feet per second at the base of the retort, the average particle of dried coal remains in the retort approximately 12 minutes. If gas is used to transport the coal, all heat of carbonization is supplied by transfer from the hot-gas zone through the retort walls. If air is used, internal combustion supplies part of the heat required. Approximately 60 percent of the heat of carbonization is supplied by combustion resulting from the use of 3 cubic feet of air to transport 1 pound of dried coal into the carbonizing system. Early tests were made with the annulus shown inside of the retort in figure 15. Clean process gas was recycled down this annulus. The gas absorbed heat from the hot wall and carried it down to the base of the retort, where the gas joined the stream entering the central retort tube. The annulus was intended to distribute the heat evenly throughout the retort and assure uniform temperatures. It was found, however, that this was unnecessary, and later tests were made without the annulus. In these later tests, all of the gas entering the retort entered with the coal stream. Leaving the top of the retort is a mixture of char, water vapor, tar and light-oil vapors, and gas. This mixture is passed through a primary separator, which removes approximately 93 percent of the solids, and is then passed through the heated secondary separator, where 70 percent of the remaining solids is removed. Vapors leaving the secondary separator are at the carbonizing temperature, usually 900° F. They are first passed through an indirect air-cooled condenser, where the heavy ends of tar and most of the carryover solids are removed. Residual vapors and gases leave the air-cooled condenser at about 340° F. and pass through a tube condenser, where they are cooled to about 150° F. The gases then pass through the steam-jacketed electrostatic precipitator, where the remaining tar is recovered, and leave the precipitator at 150° F. From here the gases go to the second indirect tube condenser to remove water and the last traces of condensable light oil. They leave the second tube condenser at 60° F. and are pumped into the recycle system or through the meter to storage or disposal.

Only one North Dakota lignite - Garrison lignite - was included in the series of coals tested in the pilot plant. Yields from the carbonization of this lignite are compared in table 22 with those from Sandow lignite from Texas processed under various operating conditions. Sandow lignite will be used to produce char for the Texas Power & Light Co. and the Aluminum Co. of America at Rockdale, Tex. (4).

Garrison lignite yielded approximately 70 percent of the amount of tar and light oil obtained from Sandow lignite under comparable processing conditions. As previously shown, North Dakota lignites in general yield less tar and light oil than Texas lignites.

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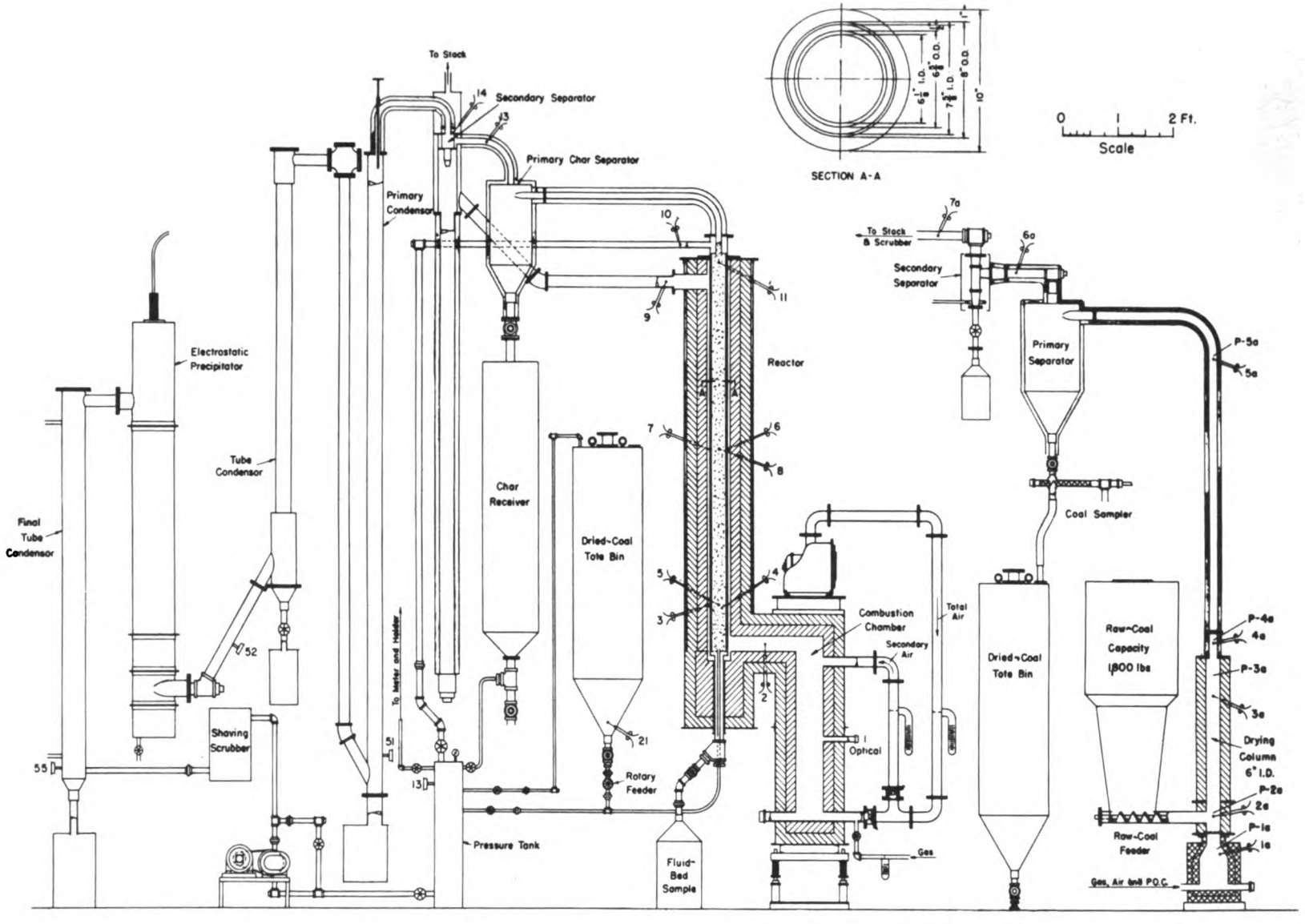

Figure 15. - Pilot plant for fluidized carbonization of noncoking coal—capacity 250 to 300 pounds per hour.

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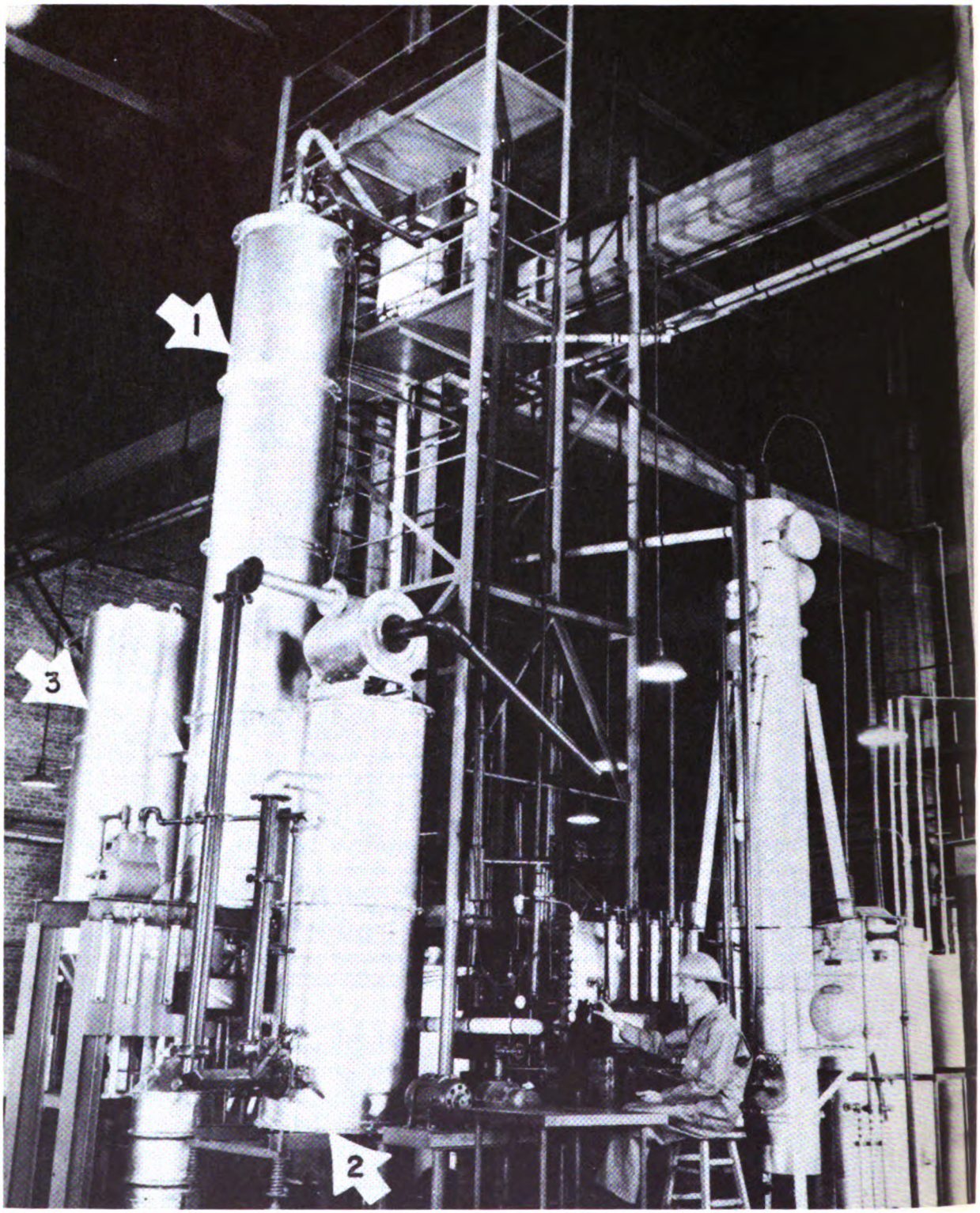

Figure 16. - Eight-inch fluidized carbonizer, Denver, Colo. (Arrow 1 points to retort and housing, arrow 2 points to combustion chamber, and arrow 3 points to dried coal hopper.

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TABLE 22.—Yield of products from lignites carbonized in 8-inch fluidized carbonizer 1/

Carbonization test No.	11		10		14		36	
Carbonization temp., °F.	840		840		900		900	
Name of lignite	Garrison		Sandow		Sandow		Sandow	
Source	N. Dak.		Tex.		Tex.		Tex.	
Moisture in lignite as mined, percent	40		35.6		35.6		35.6	
Ash in lignite as mined, percent	7.0		7.9		7.9		7.9	
Air/lb. MAF lignite, std. cu. ft.	none		none		none		2.5	
	As mined	MAF	As mined	MAF	As mined	MAF	As mined	MAF
Yields, percent 2/								
Char	48.0	77.3	52.5	78.8	49.3	73.3	46.0	67.6
Tar	3.9	7.3	6.1	10.8	6.2	10.9	7.1	12.5
Light oil	0.4	0.7	0.4	0.7	0.5	0.8	0.5	0.9
Gas	-	3/	-	3/	6.0	10.7	5.5	9.8
Water	-	3/	-	3/	37.7	3.7	39.8	7.4
Unaccounted for	-	3/	-	3/	0.3	0.6	1.1 4/	1.8 4/
Total					100.0	100.0	100.0	100.0
Yields per ton								
Char, lb.	960	1,546	1,050	1,576	986	1,466	920	1,352
Tar, gal.	-	-	-	-	15	26	16	28
Light oil, gal.	-	-	-	-	1.4	2.4	1.6	2.8
Gas, cu. ft.	-	-	-	-	1,480	2,620	3,430	6,080
Water, lb.	-	-	-	-	754	74	796	154
Gas, B.t.u./lb. of lignite	-	-	-	-	343	608	454	660

1/ Carbonizer consists of a 6.12-inch I.D. reaction tube inside an 8-inch O.D. heat-transfer tube.

2/ Yields shown represent yields of products obtained from the lignite only. The transport air used in run 36 is not included.

3/ Gas and water yields unreliable; data not reported.

4/ Includes hydrogen and carbon gasified by transport air.

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Introduction of air with the lignite during run 36 increased the capacity of the unit appreciably, since 1 cubic foot of air, by internal combustion produces approximately 100 B.t.u., of which approximately 70 B.t.u. is available for carbonization after correction for the sensible and latent heats of the products of combustion at 900° F. The yield of tar remained essentially the same whether or not air was used, and the B.t.u. in the gas per pound of lignite remained constant. Introduction of air, of course, resulted in lowering the B.t.u. per cubic foot of gas because of the dilution effects of the products of combustion. The chief effect of air appeared to be reduction of the yield of char and increasing the yields of total gas and water. The yield of tar actually increased in run 36, when air was introduced, as the result of a new shipment of Sandow lignite, which yielded 13.2 percent tar and light oil in the assay test on moisture- and ash-free basis, as compared with 12.2 percent of the Sandow lignite used during run 14.

Analyses of the chars obtained from runs 11, 10, 14, and 36 are given in table 23. Physical properties of Garrison lignite and char are listed in table 24.

TABLE 23. - Chemical analyses of char

Carbonization test No.	11	10	14	36 1/
Carbonization, temp., °F.	840	840	900	900
Name of lignite	Garrison	Sandow	Sandow	Sandow
Source	North Dakota	Texas	Texas	Texas
Proximate analysis:				
H_2O.....percent	0	0	0	0
Volatile matter..... do.	28.7	30.2	26.0	24.1
Fixed carbon..... do.	56.9	53.8	55.6	57.4
Ash..... do.	14.4	16.0	18.4	18.5
Ultimate analysis:				
H_2.....percent	3.6	3.5	3.3	3.0
C..... do.	66.8	66.6	65.9	66.6
N_2..... do.	1.3	1.5	1.4	1.5
O_2..... do.	13.3	10.9	9.1	8.9
S..... do.	0.6	1.5	1.9	1.5
Ash..... do.	14.4	16.0	18.4	18.5
Heating value.....B.t.u./lb.	11,160	11,140	10,950	10,970

1/ Air introduced, 2.5 cu. ft. per lb. MAF lignite.

TABLE 24. - Physical properties of Garrison lignite and char

	As mined	Dried	Char
Average particle size.....inches	0.082	0.041	0.019
Density.....lb./cu. ft.	41.4	40.0	35.9
Hardgrove grindability index.....	57.7	76.1	94.1

Average particle size was considerably reduced during processing, and grindability index was improved.

Composition of gases for the test runs of table 22 are presented in table 25.

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TABLE 25. - Composition of carbonization gases, 8-inch fluidized carbonizer

Carbonization test No	11	10	14	36
Carbonization temp. °F.	840	840	900	900
Name of lignite	Garrison	Sandow	Sandow	Sandow
Source	North Dakota	Texas	Texas	Texas
Air per lb. MAF lignite, std.cu.ft.	0	0	0	2.5
Volume, percent:				
H_2S	0.8	0.7	4.1	1.1
CO_2	58.5	51.6	42.4	23.2
Ill	3.9	4.9	5.7	2.6
O_2	0.3	0.3	1.4	0.2
CO	16.6	17.3	14.0	6.3
H_2	4.7	4.7	10.9	3.2
CH_4	11.3	14.2	17.8	6.5
C_2H_6	2.7	4.0	2.4	2.9
N_2	1.2	2.3	1.3	54.0
Heating value, B.t.u./cu. ft.	312	389	465	218

Increasing the carbonization temperature from 840° to 900° F. reduced the concentration of carbon dioxide and carbon monoxide and increased hydrogen and methane. Application of internal heating by introduction of air with the lignite primarily increased the nitrogen content of the gas, thereby lowering the heating value; however, because of the presence of hydrocarbons, heating value was still higher than that of conventional producer gas.

Results of assay tests have shown that about 80 percent of the heating value of the lignite was retained in the solid residue. Pilot-plant data are similar, as shown in table 26.

TABLE 26. - Distribution of potential heat per pound of lignite as charged, 8-inch fluidized carbonizer

Carbonization test No	14		36 1/	
Carbonization temperature °F.	900		900	
Name of lignite	Sandow		Sandow	
Source	Texas		Texas	
	B.t.u.	Percent	B.t.u.	Percent
Lignite, as charged	7,100	100.0	7,000	100.0
Char	5,666	79.8	5,082	72.6
Tar + light oil	1,143	16.1	1,253	17.9
Gas	348	4.9	441	6.3
Unaccounted for	-43	-.8	224	3.2
Total	7,100	100.0	7,000	100.0

1/ Air introduced, 2.5 cu. ft. per lb. MAF lignite.

The available data did not allow a heat balance to be calculated for the Garrison lignite from North Dakota. When Sandow lignite was carbonized at 900° F., the char, which was 49.3 percent of the weight of the original lignite, contained 79.8 percent of its heating value. The char and the liquid byproducts (tar and light oil) contained 95.9 percent of the heating value of the lignite. When additional internal heating by admission of air was used, B.t.u. recovered in the char were reduced to 72.6 percent whereas B.t.u. in tar and light oil did not change

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materially. The authors have therefore assumed that the air reacts primarily with the char and does not burn the liquid products of carbonization.

Since the economic success of the process depends on credits realized by sale of the liquid products, their recovery in the carbonizing equipment should approach that of the assay test, which is considered to give approximately optimum results.

In figure 17, yields obtained in the 8-inch pilot plant processing Sandow lignite at various temperatures are compared with tar-plus-light-oil yields from the 500° C. assay test.

The lower curve indicates that approximately 95 percent of tar plus light oil determined by the assay test was recovered in the pilot plant at carbonizing temperatures ranging from 900° to 950° F. The crosshatched area shows that some residual tar and light oil were left in the char, which, when added to the recovered tar and light oil, would exceed the assay yield. Low-temperature carbonization in the entrained and fluidized state in the equipment developed by the Bureau of Mines provides efficient recovery of liquid products. A high percentage of the original heating value of the lignite is recovered in a greatly reduced weight of char, which constitutes a high-B.t.u. boiler fuel.

Investigations to Produce Coherent Coke From Lignite

Char obtained from normal carbonization of United States lignites is of a loose, noncoherent nature, not suitable physically for blast-furnace use.

Laboratory studies have been made by the division of mines and mining experiments of the University of North Dakota in an effort to improve the coking characteristics of North Dakota lignite. Studies were made of the influence of the following variables on carbonization:

1. Addition of inorganic materials before carbonization.

2. Blending with bituminous coals and pitches before carbonization.

3. Mechanical pressure during carbonization.

It has been known for some time that addition of inorganic salts to either coking or noncoking coals influences both the structure of the resulting coke and its reactivity. In the tests with North Dakota lignite, various anhydrous and hydrated salts were added to samples of crushed, air-dried lignite, lignite was extracted with hydrochloric acid or sodium hydroxide solutions, and steam-dried lignite, and the mixture was then carbonized (9, 18, 19). Char, gas, and tar yields were measured and the physical structure of the char noted.

Hydrated aluminum salts, notably $Al_2(SO_4)_3.18H_2O$ and $AlCl_3.6H_2O$, caused enough cementation of char particles to produce coherent pseudocoke having, in some instances, a bright metallic luster resembling metallurgical coke and in others a black luster, as with petroleum coke. Hardness of selected cokes equaled that of petroleum coke but was less than that of metallurgical coke.

Removal of a portion of the lignite ash by acid treatment increased the effectiveness of the aluminum hydrates but did not affect char, tar, and gas yields. Prior treatment with sodium hydroxide to remove the alkali-soluble humates destroyed the effectiveness of $Al_2(SO_4)_3.18H_2O$ in producing coherent coke and decreased the char, tar, and gas yields compared to carbonization of unextracted lignite with equal additions of aluminum hydrate.

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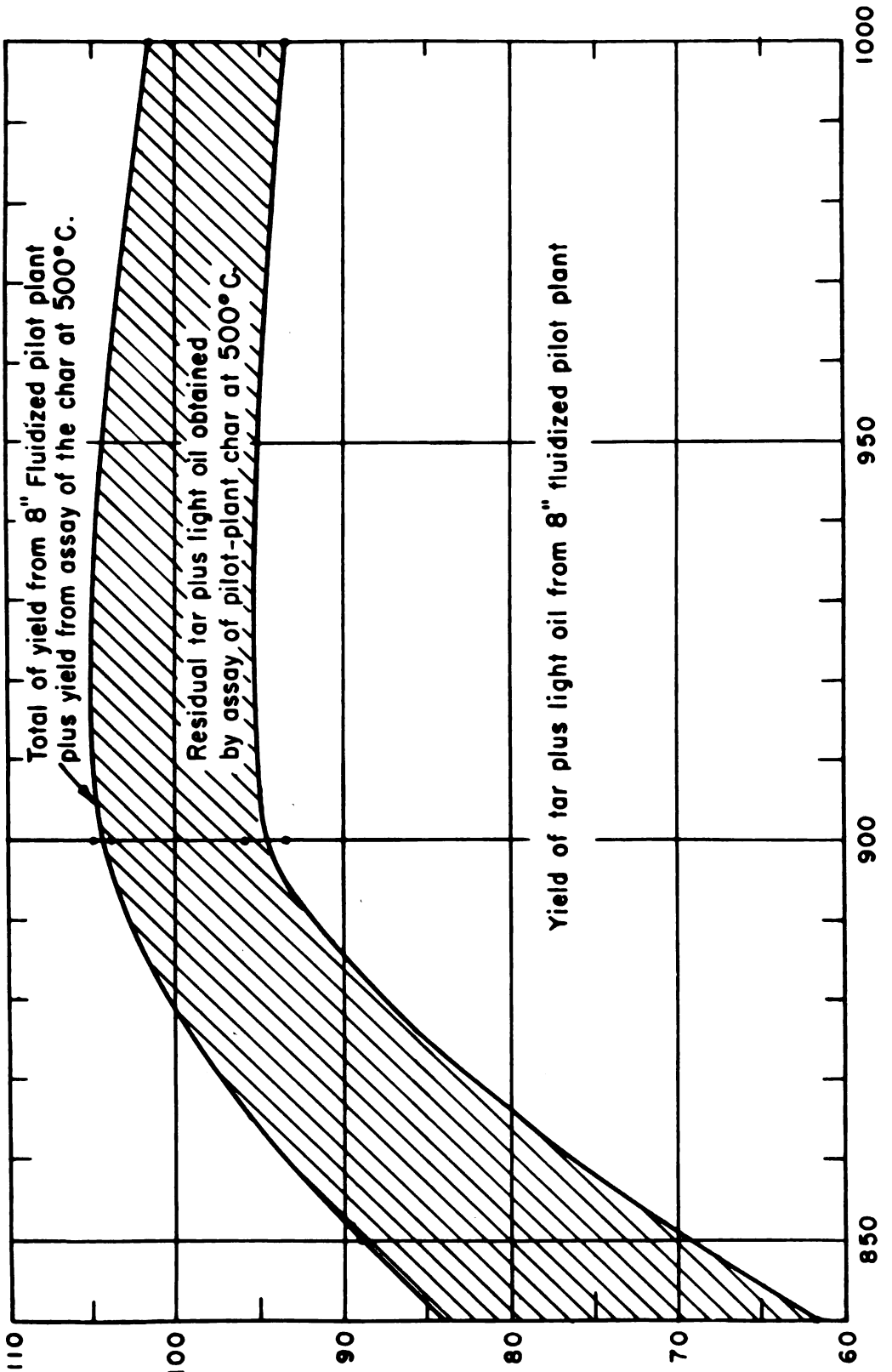
TAR PLUS LIGHT OIL YIELDS, PERCENT OF 500°C. ASSAY YIELDS
110
100
90
80
70
60
850
900
950
1000
PILOT PLANT CARBONIZING TEMPERATURE, °F.
Total of yield from 8" Fluidized pilot plant plus yield from assay of the char at 500°C.
Residual tar plus light oil obtained by assay of pilot-plant char at 500°C.
Yield of tar plus light oil from 8" fluidized pilot plant

Figure 17. - Comparison of tar plus light-oil yields from 500° C. Sandow-lignite assay with pilot plant and 500° C. char assay.

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Addition of inorganic salts to steam-dried lignite did not yield as satisfactory a coke as the nondried lignite, and tar yields were generally lower (18).

Chars produced from lignites treated with anhydrous salts, including calcium carbonate, sodium carbonate, and aluminum sulfate or chloride, were similar to untreated chars. Some additional hydrous salts investigated, such as ferric chloride hexahydrate and magnesium chloride hexahydrate, were not effective in promoting formation of coke.

The mechanism by which the pseudocoke forms is apparently one in which the melted salt dissolves in its water of crystallization and wets the surface of the lignite particles. The hydrocarbons evolved during carbonization pass through the surface film and in the presence of the inorganic matter are decomposed or cracked, forming a hard graphitic layer, which cements the carbonized particles (9).

Generally, yields of char and gas were increased somewhat and tar yield decreased when the inorganic salts were added. However, the process was not promising for commercial application because of the large amounts of hydrate required, ranging from 10 to 40 percent, by weight, of the lignite carbonized.

Carbonization properties of various blends of dried or precarbonized lignite with bituminous-coal tar, petroleum, and wheat-straw pitches or bituminous coals have been investigated (10). Only blends of Pocahontas coal and lignite char containing at least 40 percent by weight of the coal gave a satisfactory coke. Addition of hydrated inorganic salts improved the coking characteristics of the various blends.

Bituminous coal-tar pitch was not satisfactory. Petroleum pitch gave a satisfactory coke if inorganic hydrates were added. Addition of 10 percent petroleum pitch reduced the requirement of aluminum chloride hexahydrate to produce coke by a factor of 5. Pitch was prepared from straw by steam distillation or pyrolysis with yields of about 4 percent. Blends with 16 to 20 percent of straw pitch and small amounts of inorganic hydrate produced a good coke upon carbonization (10). When mechanical pressure was applied to the material undergoing carbonization, improved coking characteristics were obtained. A coherent residue could be made without adding binder or inorganic salts. However, carbonizing pressures were high, being initially some 20,000 pounds per square inch, with the final pressure somewhat less and inversely related to the carbonization temperature. The size of particles subjected to thermal treatment influenced the coke characteristics - minus-20-mesh material gave the best results. Additions of inorganic hydrate or blending material required to obtain comparable cokes were reduced when the carbonization was carried out under pressure. Again, the pressure requirements and salt additions were such that such processes could not be considered for commercial use under present technological and economic conditions.

German Processes for Carbonizing Lignite and Brown Coal

The main purpose of brown-coal carbonization in Germany was to recover tar and light oil as a source of wax, fuel oil, diesel oil, wood preservatives, and motor fuel. The resultant char was used as boiler fuel, as a source of hydrogen for hydrogenation of brown-coal tar, and to a minor extent for domestic fuel. Yields of tar and light oil as high as 17 to 22 percent on a moisture- and ash-free basis are typical for Central German brown coals, which differ significantly in composition and properties from American lignites.

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Both external and internal heating were used to supply heat for the carbonization process. External heating requires that the bed of brown coal be thin to obtain adequate rates of heat transfer and retort capacity. Provision is made to deflect the descending stream of brown coal from the externally heated wall to secure uniform heating. Because of the narrow carbonization space, the previously dried brown coal must be crushed to approximately 0.04 to 0.12 inch to maintain free flow. Advantages of external heating are: Higher heating value of the undiluted carbonization gas, smaller gas volume to be processed, and higher concentration of light-oil vapors in the gas, which facilitates light-oil recovery. However, the capacity of the carbonizers is lower than that of internally heated units. Because of the small initial size of the brown-coal particles and the further breaking up of the particles during carbonization, the char particles are very small and require careful handling to prevent spontaneous heating or dust explosion.

In conventional German practice internal heating is carried out by burning the carbonization gas in a combustion chamber and introducing the products of combustion into the carbonizer. With this method of heating, the capacity of a carbonizer unit can be very large, the size being limited by the required uniform distribution of the products of combustion through the charge. It is necessary to use a uniformly sized feed, usually briquets made from previously dried brown coal. Lignites of a consolidated nature, like North Dakota lignite, can be carbonized by internal heating in as-mined condition and need not be briquetted. Disadvantages of internal heating are: Low heating value of the gas because of dilution of products of combustion, large gas volumes, which must be processed, and the low concentration of light oil vapor in the gas, which does not permit efficient recovery by scrubbing.

Examples of externally heated carbonizers that were used commercially are the Rolle, Kosag-Geissen, and Borsig-Geissen retorts, shown in figure 18.

The Rolle retort is an improved and modified design of a carbonizer that was extensively used in the early days of brown-coal carbonization. To increase daily capacity and size of the char, the former operation on brown coal as-mined was changed to carbonization of briquets made from brown coal dried to approximately 14 percent moisture. The main parts of the Rolle retort are two cylinders hung in a cylindrical shell constructed of refractory with surrounding heating flues (30, p. 20). The upper cylinder, made of cast iron, is internally heated by gas to dry and heat the briquets to carbonization temperature in the shortest possible time. The annulus formed by the outer and inner cylinder is 12 inches wide. Water vapor and gases are withdrawn by a louverlike hood resting on top of the cast iron cylinder. Products of combustion leaving the cast-iron cylinder pass into the main flue-gas duct. The lower cylinder consists of a steel framework that supports refractory brick, each having a hole allowing the gases to escape from the annular space into the inner part of the cylinder. Gas is withdrawn at the bottom of the cylinder. Annular space in the carbonizing section is 7 inches wide. The retort has a carbonizing capacity of 12 tons of briquets per day. Tar recovery is 70 percent of the yield by Fischer assay. Because of their low capacity, only 3 plants, producing approximately 72,000 tons of tar per year, were equipped with Rolle retorts in Germany at the close of World War II.

The Kosag-Geissen and Borsig-Geissen retorts (fig. 18) also employ external heating of the carbonization space (30, pp. 22, 25). The basic design of the two retorts is similar, the latter being an improved modification of the first one. Both retorts are operated on dried and crushed brown coal, which descends between two concentric metal cylinders, the inner one of which rotates slowly and is heated by a large Bunsen-type gas burner. Baffles set in the carbonization space deflect

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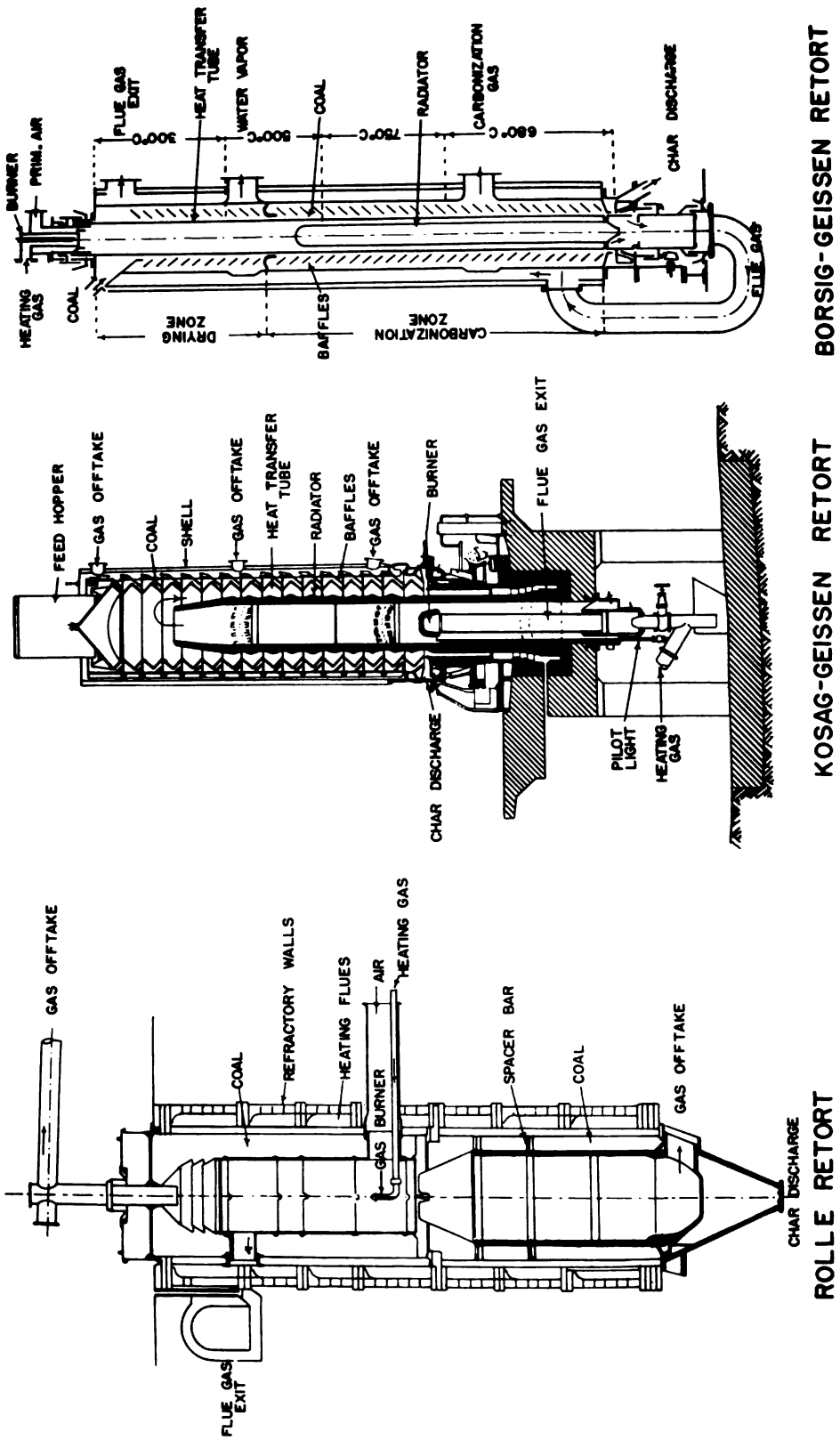

Figure 18. - Externally heated German carbonizers.

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the stream of descending coal particles to secure uniform heating. Carbonization gases pass through openings between the louverlike baffles into a gas-collecting space from which they are withdrawn through several gas offtakes. In the Borsig-Geissen retort, provision is made for flue gases leaving at the bottom of the heating chamber to be returned to an annulus surrounding the gas-collecting space to prevent formation of deposits. The main difference between the two designs is the width of the annular carbonization space, which is 2 inches for the Kosag-Geissen retort and 3/4 to 1 inch for the Borsig-Geissen retort. Reduction of the width of the carbonization space accounts for a higher capacity of the Borsig-Geissen retort per unit area of heated surface or unit volume of carbonization space.

In table 27, comparative figures are given for test runs on the two types of carbonizers (30, pp. 24, 30, 31).

TABLE 27. - Comparative figures for Kosag-Geissen and Borsig-Geissen retorts

Type of oven	Borsig-Geissen	Kosag-Geissen
Throughput/day.....tons	34.6	41.0
Moisture of brown coal.....percent	15.3	15.6
Heated surface..... sq. ft.	136	1,359
Capacity of heated surface..... .....lb./(sq. ft.)(hr.)	21.2	2.5
Volume of carbonization space.....cu. ft.	12.33	258
Capacity of carbonization space..... .....lb./(cu.ft.)(hr.)	234	13.3
Tar yield.....percent of Fischer assay	115.8	91.8

In addition to a number of Kosag-Geissen retorts, there were 22 Borsig-Geissen retorts in Germany at the close of World War II, the combined tar production of which was approximately 145,000 tons per year. A design of a large Borsig-Geissen retort, which supposedly would carbonize 120 tons of dried brown coal per day, was developed but not built.

The internally heated Lurgi-Spülgas retort (30, pp. 32-41), the same system that is in commercial use at Dickinson to carbonize North Dakota lignite, found the widest application in Germany. Basic design of the improved carbonizer is essentially like that previously shown. The capacity of a carbonization unit when using brown coal has been increased since the Dickinson plant was built. Two shafts, each approximately the size of the Dickinson carbonizer, were placed on each side of the central combustion chambers supplying the heating gases. As a result of improved distribution of heating gases, the capacity per unit volume of carbonization space was increased when brown-coal briquets were used; however, there was no substantial increase of the capacity per unit volume in direct carbonization of lignite similar to North Dakota lignite. Recovery of tar and light oil was approximately 90 percent of that obtained by Fischer assay. Heat consumption per pound of briquets containing 15 percent moisture was in the range of 900 to 1,100 B.t.u., leaving some excess gas, which was used to dry the brown coal before it was briquetted. The heating value of the stripped gas was from 180 to 215 B.t.u. per cubic foot, depending on the brown coal used. Gas obtained from carbonization was sufficient in all cases to supply heat for both carbonization and drying.

At the end of World War II 98 Lurgi-Spülgas retorts were operating in Germany, carbonizing 39,000 tons of brown-coal briquets per day, of 11 to 15 percent moisture

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content, in the production of 1,560,000 tons of tar and light oil per year. Each Lurgi-Spulgas unit thus had a carbonizing capacity of close to 400 tons of briquets per day. In addition, 80 Lurgi-Spulgas retorts were concentrated at 1 plant processing 25,000 tons of 35 percent moisture Czechoslovak lignite per day in the production of 900,000 tons of tar and light oil per year. This Czechoslovak lignite was similar in moisture content and in physical structure to North Dakota lignite. Each Lurgi-Spulgas unit had a capacity of approximately 310 tons of lignite per day.

Slightly more than 90 percent of the total low-temperature carbonization tar produced in Central Europe during World War II from briquetted brown coal and as-mined lignite was obtained from Lurgi-Spulgas retorts. The low-temperature tar was almost exclusively used as feed stock for hydrogenation plants.

Properties of Low-Temperature Lignite Tars

The temperature of carbonization influences the characteristics of tar and light oil produced from coal. True primary tars (24) are produced by techniques in which the tar vapors are swept from the carbonizing chamber without secondary thermal decomposition. Primary tars generally have low specific gravity, ranging from 0.95 to 1.05 at 25° C. High-temperature tars have a higher specific gravity of 1.15 to 1.25 at 25° C. and are relatively dark. Low-temperature tar differs essentially in composition from high-temperature tar. The composition is not well known. It contains few simple aromatic substances; complex tar acids and hydroaromatic and aliphatic substances are present. The majority of the aromatic compounds present in ordinary high-temperature tar are formed by pyrolysis during carbonization (16, p. 384).

Properties of typical low-temperature tars obtained by fluidized carbonization of lignite and subbituminous coals are compared with those from high-temperature carbonization of bituminous coals in table 28 (24).

Low-temperature tar obtained from lignite and subbituminous coals is characterized by a high concentration of tar acids, by lower yield of residue when distilled to equal temperature, and by absence of naphthalene, which is a product of rearrangement of the constituents of primary tar as a result of high temperatures.

The distribution of tar acids in tar obtained by fluidized carbonization of lignite and subbituminous coals is shown in table 29 (24).

Concentration of the commercially more desirable lower boiling acids is low. If lower boiling tar acids are desired, the high-boiling tar acids must be cracked. Development of catalytic cracking processes is now being attempted.

The method of distilling low-temperature-carbonization tars influences the relative yields of liquid distillate and solid residue. In industrial tar processing, tube-still distillation produces more liquid distillate and less pitch and fixed gas than conventional pot-still distillation. In the laboratory, distillation at reduced pressure increases the tar-distillate fraction boiling above 270° C. over and above that obtained by distillation at atmospheric pressure, with a simultaneous reduction of yield of solid residue. Since liquid products are, in general, more valuable than the solid pitch, careful consideration should be given to proper selection of the distillation processes to realize the high possible credit from the tar.

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TABLE 28. - Properties of typical low-temperature tar obtained by fluidized carbonization of lignite and subbituminous coal compared with properties of byproduct tar from coke ovens

Carbonization process	Internally heated retort, entrained + fluidized	Koppers coke oven[1/] (average)
Specific gravity of dry tar...60°/60°	1.043	1.180
Benzene insoluble..... percent	8.3	4.6
Ash in dry tar..... do.	1.0 - 3.0	-
Solidifying point..... °C.	25 - 30	-
Maximum dist. temp. ..... do.	310	300
Distillate analysis, vol.% dry tar:		
0-170° C.	2.5	0.7
170° - 200°C.	4.5	0.4
200° - 210°C.	3.5	0.7
210° - 235°C.	8.0	5.3
235° - 270°C.	12.0	11.1
270° - end point.....	24.5	8.1
Total distillate.....	55.0	26.3
Pitch residue and loss.....	45.0	73.7
Tar acids.....vol. % dry tar	20.0	2.01
Tar bases..... do.	2.0	-
Neutral oil..... do.	40.0	-
Naphthalene in 170° - 235°C. fraction.....vol. % dry tar	0.0	7.45
Composition of neutral oil, vol. % dry tar:		
Olefins	12.0	-
Aromatics.....	20.0	-
Paraffins.....	8.0	-
Pitch residue:		
Melting point....cube in air....°C.	110	-
Melting point...ring and ball...do.	-	48.5
Specific gravity..... 25°/25°	1.200	-

1/ Rhodes, E. D., Chapter in Chemistry of Coal Utilization: Vol. II, John Wiley & Sons, 1945, pp. 1287-1325.

TABLE 29. - Distribution of tar acids in primary tars

Tar acids	Boiling range, °C.	Volume percent of tar-acid fraction	Volume percent of total tar
Phenol.....	0 - 183	2.0	0.4
O-cresol.....	183 - 190	1.0	.2
m- and p-cresol.....	190 - 200	3.0	.6
Isomeric xylenols.....	200 - 233	28.0	5.5
High boiling acids.....	233 - 285	23.0	4.5
Acid residue.....	Above 285	43.0	8.5

When lignite and subbituminous coal tars were subjected to atmospheric or vacuum distillation in the laboratory, it was noted that lignites produced the greater quantity of distillate rich in high-boiling fractions; the effect was more pronounced in the distillate produced by distillation under reduced pressure. Tar from subbituminous coals showed a greater spread of the distillation products by the two distillation techniques.

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Preliminary characterization data on properties of lignite tar obtained from Texas and North Dakota lignite by the fluidized, entrained technique are given in table 30. It may be noted that the temperature of carbonization was 900° F. for attrital Sandow lignite, whereas it was 840° F. for woody garrison lignite. Both temperature and different petrographic composition may contribute to the different characteristics of the tars. Decomposition temperature of the Garrison tar is distinctly lower than that of Sandow lignite, which accounts for the lower yield of distillate. The concentration of tar acids is appreciably higher for the woody Garrison lignite than for Sandow lignite.

No analyses are available for the light oil that can be extracted from the gas in fluidized carbonization. Properties of light-oil extracted from the gas of a Lurgi-Spulgas retort processing German brown coal briquets are given in table 31 (30, p. 289)

Our present knowledge of the properties and potential uses of low-temperature lignite tar is of rudimentary nature because work on this subject is limited. Extensive work on chemical composition, products obtainable, and potential uses, which is now being carried out at various laboratories, should permit more accurate estimation of credits obtainable.

Uses for Products From Low-Temperature Carbonization of Lignite

The chief products from low-temperature carbonization of lignite are char, tar and light oil, and gas. Char is the most important product on a weight basis, being approximately 45 to 50 percent of the lignite as mined. The char contains about 80 percent of the original heating value of the lignite when external heating or internal heating by inert gases is used. Partial internal heating by introducing air with the lignite reduces this figure to 73 to 75 percent.

Because the yield of tar and light oil from North Dakota lignite is only about 4 to 6 percent of the weight of the lignite as mined, only processes that consume large quantities of char can make tar available in quantities sufficient for processing it for maximum realization.

The most logical large-scale outlet for char is utilization as boiler fuel for large power plants or industries that consume large quantities of process steam. To make utilization of char as a boiler fuel attractive, the cost per million B.t.u. at the point of consumption must be equal to or less than that of competitive industrial fuels. Where the power plant is close to the mine, char must compete with as-mined lignite. Since the char contains only 80 percent of the heating value of the lignite, more lignite is initially required to make available equal amounts of B.t.u. than would be necessary when raw lignite is fired directly. One million B.t.u. is equivalent to 143 pounds of as-mined lignite or to 91 pounds of char when the heating values are 7,000 B.t.u. per pound and 11,000 B.t.u. per pound, respectively. Since the yield of char is approximately 50 percent of the weight of the lignite, 182 pounds of raw lignite is required to produce the amount of char equivalent to 1 million B.t.u. Tar credit must pay for the cost of carbonization and for the additional raw-material requirement.

An additional small credit will be obtainable at the boiler plant when char is used because of the reduced tonnage of fuel to be handled and the increased efficiency of the boiler furnaces.

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TABLE 30. - Properties of low-temperature primary tars obtained from fluidized carbonization of lignites (12)(24)

Carbonization run No.	36		11	
Coal	Sandow, Tex.		Garrison, N. Dak.	
Temp. of carbonization, °F.	900		840	
Spec. gravity of dry tar, 60°/60°	1.062		1.054	
Benzene-insoluble in dry tar, percent	8.1		19.1	
	Atmos[1]	Vacuum[1]	Atmos[1]	Vacuum[1]
Maximum dist. temp. or initial decomp. temp. of dry tar[2], °C.	310	284	250	206
Decomp. temp. of distillate[3], do.	346	360	286	280
Distillate to decomp. temp., vol. % of dry tar	51.7	70.6	42.0	38.8
Distillate analysis, vol. % of dry-solids-free tar:[4]				
To 170° C.	4.0	2.3	1.9	1.0
170° - 200° C.	2.7	3.8	3.1	1.4
200° - 210° C.	2.7	3.3	3.9	2.3
210° - 235° C.	7.5	5.8	9.4	9.2
235° - 270° C.	9.2	10.7	13.9	14.4
270° - decomposition	22.7	40.2	5.0	6.0
Residue and loss	2.9	4.5	4.8	4.5
Composition of distillate, vol. %:				
Acids	29.8	32.2	66.8	64.8
Bases	3.4	4.0	3.2	6.0
Neutral oil	66.8	63.8	30.0	29.2
Distillate yield, vol. % of dry-solids-free tar:				
Acids	15.4	22.7	28.1	25.2
Bases	1.8	2.8	1.3	2.3
Neutral oil	34.5	45.1	12.6	11.3
Composition of neutral oil, vol. %:				
Olefins	31.1	59.1	43.3	47.8
Aromatics	32.4	24.1	35.4	29.2
Paraffins	36.5	16.8	21.3	23.0
Distillate yield, vol. % of dry-solids-free tar:				
Olefins	10.7	26.7	5.4	5.4
Aromatics	11.2	10.9	4.5	3.3
Paraffins	12.6	7.5	2.7	2.6
Pitch residue, melting point:				
Cube in air, °C.	5/114	5/147	118	92
Ring and ball, do.	110	135	-	-
Specific gravity, 25°/25°	1.169	1.160	1.204	1.184

1/ Atmospheric distillation at 620 mm.; vacuum distillation at 40 mm. absolute.
2/ Indicated vapor temp. at decomp. point in first distillation separation.
3/ Second distillation (Hempel) made at 620 mm. on both type distillates.
4/ By Hempel distillation.
5/ In glycerol.

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TABLE 31. - Properties of light oil from German brown-coal briquets

Specific gravity at 20° C.	0.851
Tar acids.....weight.....percent	10.1
Distillate analysis (Engler), vol. %:	
To 60° C.	1.4
60° - 80° C.	6.3
80° - 100° C.	14.9
100° - 120° C.	29.7
120° - 140° C.	42.5
140° - 160° C.	60.5
160° - 180° C.	73.7
180° - 200° C.	80.0
200° - 220° C.	98.1
Composition of tar acids, wt. %:	
Phenol	32.0
o-cresol	17.3
m-cresol	10.4
p-cresol	18.0
Isomeric xylenols	22.3

Where char is to be shipped, the question of freight charges enters the picture because of reduced tonnage on an equal B.t.u. basis. However, freight rates applying to char would first have to be known before any shipping advantage can be finally evaluated. Special handling to avoid spontaneous ignition would also have to be considered.

Large-scale consumption of char in form of briquets for domestic fuel use does not seem promising in the light of declining utilization of solid fuels for domestic heating under present conditions.

Other potential applications for lignite char are the manufacture of electrodes and the production of calcium carbide; the latter requires cheap power and availability of limestone. Because of its high reactivity, lignite char should be an efficient agent for reducing ores in processes not requiring a physically coherent coke. It might be used for partial reduction of nonmagnetic taconite as the first step of the magnetic concentration.

Char from brown coal, which is somewhat similar to that from lignite, has been extensively used in Germany to produce synthesis gas and hydrogen. Possible utilization of lignite char is more a question of cost than of quality. Therefore, the future development of low-temperature carbonization of lignite depends to a large extent on profitable use of byproducts, chiefly the tar.

Lignite tar is a suitable source material for manufacturing aromatic hydrocarbons and liquid fuels by the hydrogenation process. Hydrogenation of tar is simpler and requires less hydrogen than direct hydrogenation of coal. Tar acids recovered from processing low-temperature tar are suitable wood preservatives (25). If the more valuable lower boiling tar acids are desired, the high-boiling acids must be catalytically cracked. These acids have been used in lacquers and plastics in Germany (28, p. 37).

The gas produced in internally heated, low-temperature-carbonization processes is commonly consumed in the process itself, which seems to be the most

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desirable utilization. Because of its low heating value, pipeline transportation would be uneconomical. Heating value of carbonization gas from internally heated processes approaches that of producer gas.

Bibliography

1. BABCOCK, E. J. Economic Methods of Utilizing Western Lignites. Bureau of Mines Bull. 89, 1915, 73 pp.

2. BABCOCK, E. J., AND ODELL, W. W. Production and Briquetting of Carbonized Lignite. Bureau of Mines Bull. 221, 1923, 82 pp.

3. BRITISH INTELLIGENCE OBJECTIVES SUBCOMMITTEE. Drying, Briquetting and Low-Temperature Carbonization of Brown Coal in Lurgi-Spülgas Retorts. Final Rept. 626, Item 30.

4. CHEMICAL ENGINEERING. Lignite Process Hits the Mark. September 1951, pp. 219-222.

5. CHEMICAL WEEK. Tar and Char, Power Too. Aug. 18, 1951, pp. 25-26.

6. DARLING, S. M. The carbonizing and Briquetting of Lignite. Rept. of Investigations to Government of Province of Saskatchewan, 1915, 47 pp.

7. DAVIS, J. D., AND GALLOWAY, A. E. Low-Temperature Carbonization of Lignites and Subbituminous Coals. Ind. Eng. Chem., vol. 20, No. 6, 1928, pp. 612-617.

8. FIELDNER, A. C. Low-Temperature Carbonization of Coal. Bureau of Mines Tech. Paper 396, 1926, 46 pp.

9. GAUGER, A. W. The Influence of Inorganic Materials on Lignite Carbonization. Proc. 2d Internat. Conf. Bit. Coals, vol. 1, November 1928, pp. 312-328.

10. GAUGER, A. W., TAYLOR, J. R., AND ULMAN, C. W. Effects of Blending and Mechanical Pressure on Coking of Lignite. Ind. Eng. Chem., vol. 24, 1932, pp. 36-40.

11. GLENK, R. Louisiana Lignite. State of Louisiana, Dept. of Conservation Bull. 8, 1921, 65 pp.

12. GOMEZ, M., AND GOODMAN, J. B. Distillation Assays of Missouri River Basin Coals. Bureau of Mines Rept. of Investigations 5009, 1953, 9 pp.

13. GOODMAN, J. B., GOMEZ, M., PARRY, V. F., AND LANDERS, W. S. Low-Temperature Carbonization Assay of Coal in a Precision Laboratory Apparatus. Bureau of Mines Bull. 530, 1953, 24 pp.

14. HALL, R. D. North Dakota Plant Carbonizes Lignite at Mine Mouth and Briquets Resultant Char for Shipment. Coal Age, vol. 45, August 1940, pp. 47-48.

15. HOOD, O. P., AND ODELL, W. W. Investigations of the Preparation and Use of Lignite, 1918-25. Bureau of Mines Bull. 255, 1926, 204 pp.

16. KARRER, P. Organic Chemistry. Elsevier Publishing Co., Inc., New York, Amsterdam, London, Brussels, 4th English ed., 1950, 983 pp.

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17. KERSCHBAUM, F. P. Modern Developments in Lignite Carbonization. Proc. 2d Internat. Conf. Bit. Coal, Nov. 19-24, 1928, vol. 1, pp. 283-302.

18. KOTH, A. W., AND LAVINE, I. Effect of Inorganic Materials on Low-Temperature Carbonization of Lignite. Ind. Eng. Chem., vol. 25, 1933, pp. 328-333.

19. _____. Effect of Inorganic Materials on Reactivity of Low-Temperature Lignite Char. Ind. Eng. Chem., vol. 25, 1933, pp. 570-574.

20. MANUFACTURERS RECORD. Lignite to be Fuel at New Alcoa Plant in Texas. Vol. 120, October 1951, pp. 44-45.

21. ODE, W. H. AND SELVIG, W. A. Low-Temperature Distillation Yields of Primary Tar and Light Oil From Coals of Various Ranks and Types. Bureau of Mines Rept. of Investigations 3748, 1944, 10 pp.

22. ODELL, W. W. Report of Carbonizing Experiments Conducted at Grand Forks in 1922. Bureau of Mines Rept. of Investigations 2441, 1923, 26 pp.

23. PARRY, V. F., GOODMAN, J. B., AND GOMEZ, M. Low-Temperature Distillation Assays of Representative Western United States and Alaska Coals. Colorado School of Mines Quart., vol. 45, No. 2A, April 1950, pp. 133-162.

24. PARRY, V. F., LANDERS, W. S., GOODMAN, J. B., AND LAMMERS, G. C. Drying and Carbonizing Fine Coal in Entrained and Fluidized State. Bureau of Mines Rept. of Investigations 4954, 1953, 43 pp.

25. PROSTEL, E. Creosote Derived From Low-Temperature Distillation of Lignite Coal. Proc. Am. Wood - Preservers Assoc., vol. 45, 1949, pp. 62-65.

26. REYNOLDS, D. A., AND HOLMES, C. R. Procedure and Apparatus for Determining Carbonizing Properties of American Coals by the Bureau of Mines - American Gas Association Method. Bureau of Mines Tech. Paper 685, 1946, 35 pp.

27. REYNOLDS, D. A., DAVIS, J. D., ODE, W. H., WOLFSON, D. E., AND BIRGE, G. W. Carbonizing Properties of Velva Lignite From Ward County, N. Dak., and Monarch Coal From Sheridan County, Wyo. Bureau of Mines Tech. Paper 695, 1946, 41 pp.

28. RHODES, E. O. German Low-Temperature Coal-Tar Industry. Bureau of Mines Inf. Circ. 7940, 1949, 84 pp.

29. SELVIG, W. A. Properties of Lignites of the United States. Fuel, vol. 32, No. 1, January 1953, pp. 28-35.

30. THAU, A. Brennstoffschwelung, vol. 1, Schweltechnik und Schwelbe-trieb, Wilhelm Knapp, Halle, 1949, 395 pp.

31. YANCEY, H. F., JOHNSON, K. A., AND SELVIG, W. A. Friability, Slacking Characteristics, Low-Temperature Carbonization Assay, and Agglutinating Value of Washington and Other Coals. Bureau of Mines Tech. Paper 512, 1932, 94 pp.

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3. GASIFICATION

Two types of gasification products will be discussed in this section, synthesis gas and producer gas. Producer gas is produced by blowing air through a solid fuel bed with or without the addition of steam. It results in a low-heating-value, inexpensive gas with a high percentage of nitrogen. The production of synthesis gas requires more expensive methods to satisfy the heat demand of the endothermic reaction of the carbon of the fuel with steam because dilution of the process gas with nitrogen is undesirable. Oxygen may be introduced to supply the required heat internally by burning a portion of the fuel. Alternatively heat may be transferred through externally heated walls of the reactor, or a cyclic process with separate periods of heating and gasification may be used, such as the conventional water-gas set. The usable constituents of synthesis gas, for most applications, are carbon monoxide and hydrogen.

Synthesis Gas

Although the preparation and use of cartain types of synthesis gas are not new, developments of the last few years have markedly increased the interest in new gasification methods (27).1/ In modern gasification processes, use of "tonnage oxygen" to secure the heat necessary for the process by partial combustion of the solid fuel and use of high pressures have considerably altered gasification techniques. These, together with fuel preparation and other variations, have given rise to a number of types of gasification processes. Some of these gasification processes were originated in Europe and have received further development work in the United States. This work and the processes originated by organizations in the United States will be described in this section of the report, and the European work will be covered in part 1.

Representative processes and variations in operation are presented in table 32.

TABLE 32. - Modern synthesis-gas processes

Size of fuel	Operating pressure	Heat supply for consumption by gasification process		
		Internal heating		External heating
		With oxygen	Preheated recirculating gases	
Coarse nut size or briquet	Atmospheric	Thyssen-Galoczy Leuna slagging	Pintsch-Hillebrand	Didier-Bubiag Bureau of Mines, Grand Forks, N. Dak. Freiberger
	Elevated pressure	Lurgi		
Small particle in suspension	Atmospheric	Winkler Bureau of Mines, Morgantown, W.Va. DuPont-Babcock and Wilcox Koppers Coal Syndicate	Schmalfeldt-Wintershall	Battelle process
	Elevated pressure	Texas Co. process Bureau of Mines, Morgantown, W.Va.		

1/ Underlined numbers in parentheses refer to citations in the bibliography at the end of this section.

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It would be impossible to cover each of the processes in detail; however, the following discussion presents a short description of the main types and pertinent operating data.

Externally Heated Annular Retort, Bureau of Mines, Grand Forks, N. Dak.

The Bureau of Mines at Grand Forks, N. Dak., has been experimenting with an externally heated retort for gasification of lump lignite at atmospheric pressure. A diagram of this retort is shown in figure 19. This unit, which has been developed as a commercial-scale pilot plant, consists basically of two concentric steel cylinders separated by a 3-inch annular space. The outer steel cylinder of 310 alloy composition is 4 feet i.d., 20 feet 6 inches long. Approximately 17 feet of its length is heated by a surrounding cylindrical furnace. The furnace consists of a combustion space 7 inches wide, with 18-inch thickness of brick refractory outer wall. Burners are set tangentially in this wall around the tube at three levels to secure temperature control over the length of the tube.

Lignite 1-1/2 by 3/8-inch in size is fed to the charging dome at the top of the retort using a rotary feeder, to maintain the charging dome partly full. The lignite descends slowly by gravity through the annular space between the two cylinders, where the gasification takes place. A residue consisting of ash and char is removed continuously from the bottom of the retort. The lignite feed rate is controlled, at a given gasification rate, by adjusting the rate of residue removal. The product gas flows from the annulus into the center of the inner tube through the gas offtake. This offtake is located, depending upon the type of inner tube in use, at either the bottom of the annulus or at a point approximately one-third of the tube length from the bottom. The gas leaves at the top of the retort and enters the scrubbing system. Using the full-length annulus design, where the gas offtake is near the bottom, steam is admitted only with the lignite feed. With the divided annulus arrangement, steam is added both to the upper and lower reaction zones. In the full-length annulus design, saturated steam is introduced at the top of the annular space through a jacket surrounding the gas offtake pipe. The lignite is dried in the upper portion of the unit by heat from the outer wall, and the additional steam generated also enters into the process. As the temperature of the lignite increases, tars and light oils distill. These are cracked and undergo reaction with the steam at lower levels. Gas formed by this reaction and by the reaction of the steam with the solid carbon of the lignite is withdrawn through the inner steel cylinder. A portion of the sensible heat of the gas is transferred to the lignite, especially at the higher levels, through the inner cylinder wall.

In the experimental work a portion of the product gas is used for heating the retort. Air, preheated in a heat exchanger, is mixed with the gas at the flame nozzle, and some of the products of combustion are recycled with this air to reduce the flame temperature, lengthen the flame travel, and provide a greater bulk of gases.

The 310 alloy steel tube has given satisfactory service, and only negligible corrosion and minor deformation of the tube have resulted from 4,740 hours at high temperature. Plant operation has been stable with no major difficulties. Runs normally were made continuously for 1 month and terminated only because the program of the tests had been completed.

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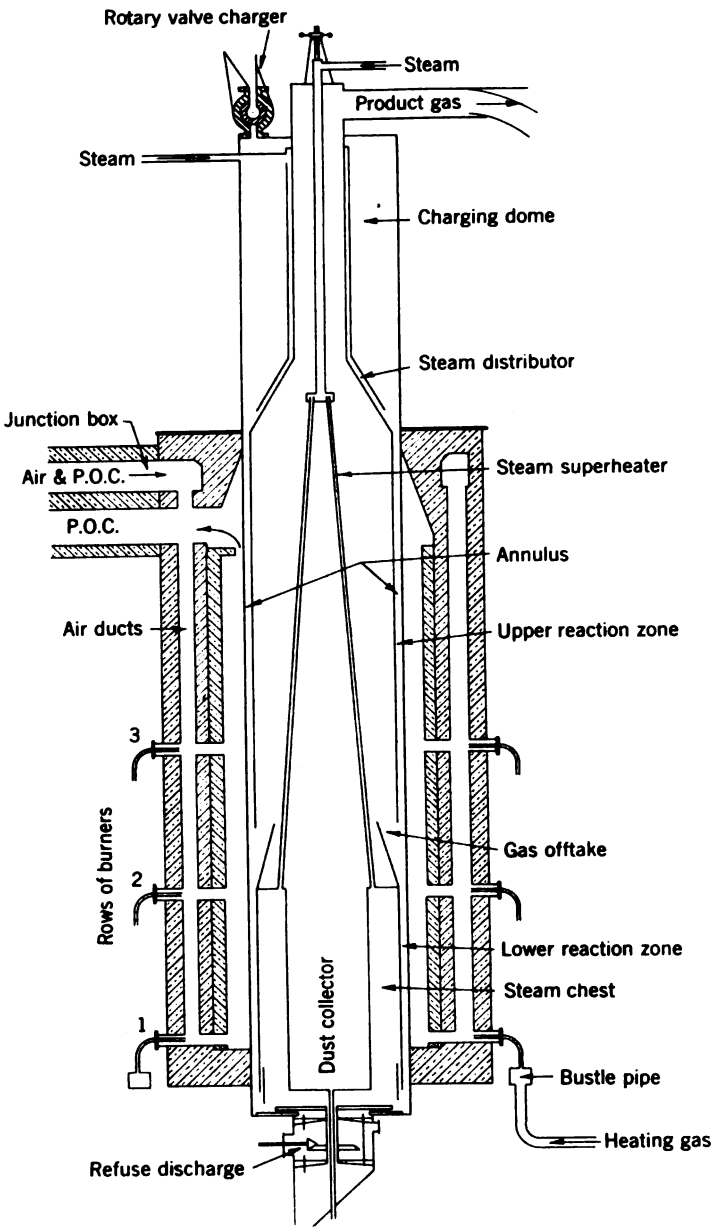

Figure 19. - Bureau of Mines externally heated gasifier, Grand Forks, N. Dak.

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Data from the operation of the pilot plant are presented in table 33. Additional information on this plant is available in several publications (7, 8, 11, 12, 23, 24, 25). It will be noted that the capacity of the generator is increased when steam-dried lignite is used. This is the result of reducing the length of the annular space required for drying the fuel and consequent increase in the heat available for gasification. Although a variety of gas ratios may be made in this unit, the most practical operation is secured at the H_2:CO ratio of 2.0, the lowest ratio readily obtainable.

TABLE 33. - Typical results with externally heated retort, Bureau of Mines, Grand Forks, N. Dak.

Lignite gasified	Natural Dakota Star	Natural Dakota Star	Steam-dried Dakota Star
Run and period	11-M	11-A	12-D
Combustion space temp., °F.			
1	1,750	1,926	1,926
2	1,802	1,853	1,850
3	1,579	1,758	1,690
4	1,461	1,600	1,597
Lignite feed rate, lb./hr.	343	641	489
Moisture and ash free lignite, do.	197	390	392
Steam addition:			
A. Available from lignite moisture + H_2O of formation, lb./hr.	165	310	158
B. Fed to top of annular reaction space, lb./hr.	309	68	257
C. Fed to bottom of annular reaction space, lb./hr.	308	210	198
D. Total steam available:			
Lb./hr.	782	588	613
Lb./lb. MAF lignite	3.97	1.56	1.56
Undecomposed steam, lb./hr.	342	281	208
Decomposed steam:			
Lb./hr.	440	307	405
Percent of total steam available	56.7	52.2	66.0
Product gas:			
M std. cu. ft./hr.	10.6	12.6	16.4
Std. cu. ft./lb. MAF lignite	53.8	32.4	41.7
Product (H_2 + CO):			
M std. cu. ft./hr.	7.7	9.7	13.4
Std. cu. ft./lb. MAF lignite	39.1	24.9	34.2
Carbon gasified, percent	86.6	57.3	76.0
Heat used, net B.t.u./cu. ft. of product gas	119	122	98
Product gas for heating, percent of gas made	53.8	48.3	37.9
Product gas composition, percent:			
CO_2	24.1	18.3	14.6
Illuminants	0.1	0.2	0.0
CO	11.0	19.0	24.9
H_2	61.7	57.9	57.0
CH_4	2.3	3.8	2.9
C_2H_6	0.3	0.3	0.1
N_2	0.5	0.5	0.5
H_2/CO ratio	5.59	3.04	2.29

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Table 34 (7) presents data covering heat transfer through the metal wall of the retort.

TABLE 34. - Heat-transfer and operating data, externally heated retort, Bureau of Mines, Grand Forks, N. Dak.

Range	Overall heat transfer through retort tube[1]								
	Low			Medium			High[2]		
Run and period.....	11-G	11-K	11-L	11-C	11-M	13-M	12-A	12-C	12-D
Heat transfer..... .....B.t.u./sq.ft./hr.	2,100	2,300	2,300	3,200	3,300	3,200	4,400	4,300	4,200
H_2/CO ratio of gas.....	4.84	3.57	3.99	2.75	5.59	3.77	1.85	2.30	2.29
Lignite feed rate.....lb./hr.	389	359	404	500	343	451	481	445	489
Carbon gasified..... percent	75.0	68.4	67.2	69.4	86.6	77.5	65.3	76.1	76.0
Product gas.....M cu. ft./hr.	10.2	8.5	9.2	11.7	10.6	11.7	14.0	14.6	16.4

1/ Files: Bureau of Mines, Grand Forks, N. Dak.
2/ Experiments made with steam-dried lignite.

Representative analyses of Dakota Star lignite charged to gasifier

Analysis, percent	Natural lignite		Steam-dried lignite	
	As received	Moisture free	As received	Moisture free
Proximate:				
Moisture	34.2		13.3	
Volatile matter	28.5	43.3	38.3	44.2
Fixed carbon	30.5	46.3	41.3	47.7
Ash	6.8	10.4	7.1	8.1
Ultimate:				
Hydrogen	6.7	4.3	5.8	4.3
Carbon	42.6	64.8	56.7	65.7
Nitrogen	.6	.9	.7	.9
Oxygen	42.4	18.3	28.6	19.6
Sulfur	.9	1.3	1.2	1.4
Ash	6.8	10.4	7.0	8.1
B.t.u./lb.	7,160	10,880	9,570	11,030

Externally Heated Retort for Pulverized Coal, Battelle Memorial Institute

Experimental work utilizing external heating with pulverized lignite has been completed at the Battelle Memorial Institute at Columbus, Ohio (16).

In this process, gasification was carried out in a vertical steel reaction tube, which was heated over the greater part of its length by a surrounding gas-heated furnace. The pulverized coal was fed at the top of this reaction tube, and the products of gasification were withdrawn from the bottom. Two reactor tubes were used at different times during the experiments - one a 5-inch-i.d. tube of 25-12 chromium-nickel alloy, and the other a 8.25-inch-i.d. tube of 25-12 chromium-nickel alloy. Both tubes were 11 feet long and were heated over a length of approximately 9 feet. Pulverized coal was fed from a rotary table feeder through an adapter incorporating a venturi section, steam being admitted at the venturi throat.

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Gasification occurred along the tube length, and the solids entrained in the gas stream were removed by gas baffles in the ash receiver. The gases then were scrubbed.

The lignite utilized in the tests was subjected to some type of drying, and in the article (16) it was stated that the gasification characteristics were affected appreciably by the drying methods. Activity of lignite dried at 220° F., as determined in terms of a calculated gasification constant, was over 25 percent less than for lignite dried in air at 100° F., or for steam-dried lignite.

Data covering the analysis of the fuel used and the results of the gasification are presented in table 35 (16).

TABLE 35. - Operating data for the Battelle externally heated gasifier

Run No.	39	45	49
Tube diameter, ft.	0.407	0.687	0.687
Tube temperature, °F.	2,098	2,047	2,025
Lignite feed rate, lb./hr.	16.0	21.8	49.4
Steam rate, do.	21.6	26.0	50.2
Excess steam, percent	58	39	18
Gas produced, cu. ft./hr. at standard conditions	552	793	1,264
Gas composition, percent:			
CO_2	9.4	7.8	10.8
O_2	1.5	.7	.7
CO	31.5	33.8	29.3
CH_4	3.2	3.7	5.4
H_2	50.2	49.6	48.9
N_2 1/	4.2	4.4	4.9
Gross heating value, B.t.u./cu.ft.	297	308	308
Gas temperature at tube exit, °F.	-	-	1,602

1/ Presumed to be present because of air leak in apparatus.

Lignite analysis: Air-dried at 220° F. to 11.5 percent moisture

Proximate analysis, percent:		Ultimate analysis, percent:	
Moisture	11.5	Carbon	57.2
Volatile matter	38.0	Hydrogen	5.1
Fixed carbon	43.8	Oxygen	29.7
Ash	6.7	Nitrogen	.9
		Sulfur	.4
		Ash	6.7
Total	100.0	Total	100.0

Heating value, B.t.u./lb. 9,540

The heat transfer of the Battelle externally heated unit has been calculated from the data presented in table 35. It appears that the heat-transfer rates attained with the Battelle gasifier are comparable, with a maximum of 4,500 B.t.u. and a minimum of 3,200 B.t.u. per square foot per hour, to those attained with the Grand Forks externally heated retort.

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For translation of this process to a commercial scale, it was proposed that a number of tubes of approximately the same diameter and 27 feet long be placed in a common furnace heated by pulverized fuel. However, the calculations made regarding the practicability of the process resulted in the conclusion that the investment cost would be unfavorable, and no further studies were made.

Koppers Pulverized-Fuel Process

The Koppers pulverized-fuel process was originated in Germany on the pilot-plant scale but had not been used commercially before the end of World War II.

A diagram of a typical Koppers unit is shown in figure 20 (21).

Basically, the unit consists of two facing nozzles set at opposite ends of a generator. Oxygen and fuel are fed through the nozzles, and superheated steam enters around each nozzle. The two nozzle streams upon meeting cause turbulence, and fuel-O_2-steam reaction is reasonably complete in the area between the nozzles. The remainder of the reaction occurs in the vertical cylinder leading to the gas outlet above the unit. The larger ash particles, not carried off by the gas stream, fall into ash collectors at the bottom of the reactor.

A unit built for experimental work at Louisiana, Mo., (3, 4) has a generator space 6-1/2 feet i.d. and 9 feet long. Considerable mechanical difficulty has been encountered in operating this particular unit, as well as difficulty in reaching the anticipated operating efficiency. Although the unit was not operated on lignite, some data are presented in table 36 (19) on a low-rank coal from Rock Springs, Wyo.

Bureau of Mines Atmospheric-Pressure Gasifier, Morgantown, W. Va.

The atmospheric-pressure gasifier at Morgantown, designed and built in cooperation with the Babcock & Wilcox Co., was completed in 1951. Information regarding this unit is available in several Bureau of Mines reports (5, 6, 29). Several changes in design have been made in the course of experimental work. The most recent arrangement is shown in figure 21. The gasifier is a vertical, cylindrical column lined with refractory materials. It is divided by restricting refractory material into two zones, with the primary reaction zone at the bottom and the secondary reaction zone above. The refractory lining in the primary zone is protected by cooling coils, which also are used to support the upper brickwork at the point of restriction. Pulverized coal, preheated to about 325° F. in a steam-coil heater, is intimately mixed with oxygen and steam in a reactant injection nozzle to secure turbulence. These nozzles are placed to direct the coal, oxygen, and steam into the reaction chamber at an angle 32° from the vertical and tangential to a circle of 12 inches diameter. A small percentage of the gas made 10 to 15 percent passes downward through the slag throat and insures a flow of slag. Approximately 40 percent of the coal ash is removed as slag and contains little or no carbon.

The major portion of the product gas is removed at the top, after passing through the secondary reaction and gas-cooling zones. The remainder of the ash is entrained with this gas as a finely divided residue containing approximately 60 percent carbon. Although this unit has been described as a slagging type, it also has been operated satisfactorily under nonslagging conditions. The carbon accompanying the ash has not caused difficulty, and no deposits formed on the cooling surfaces.

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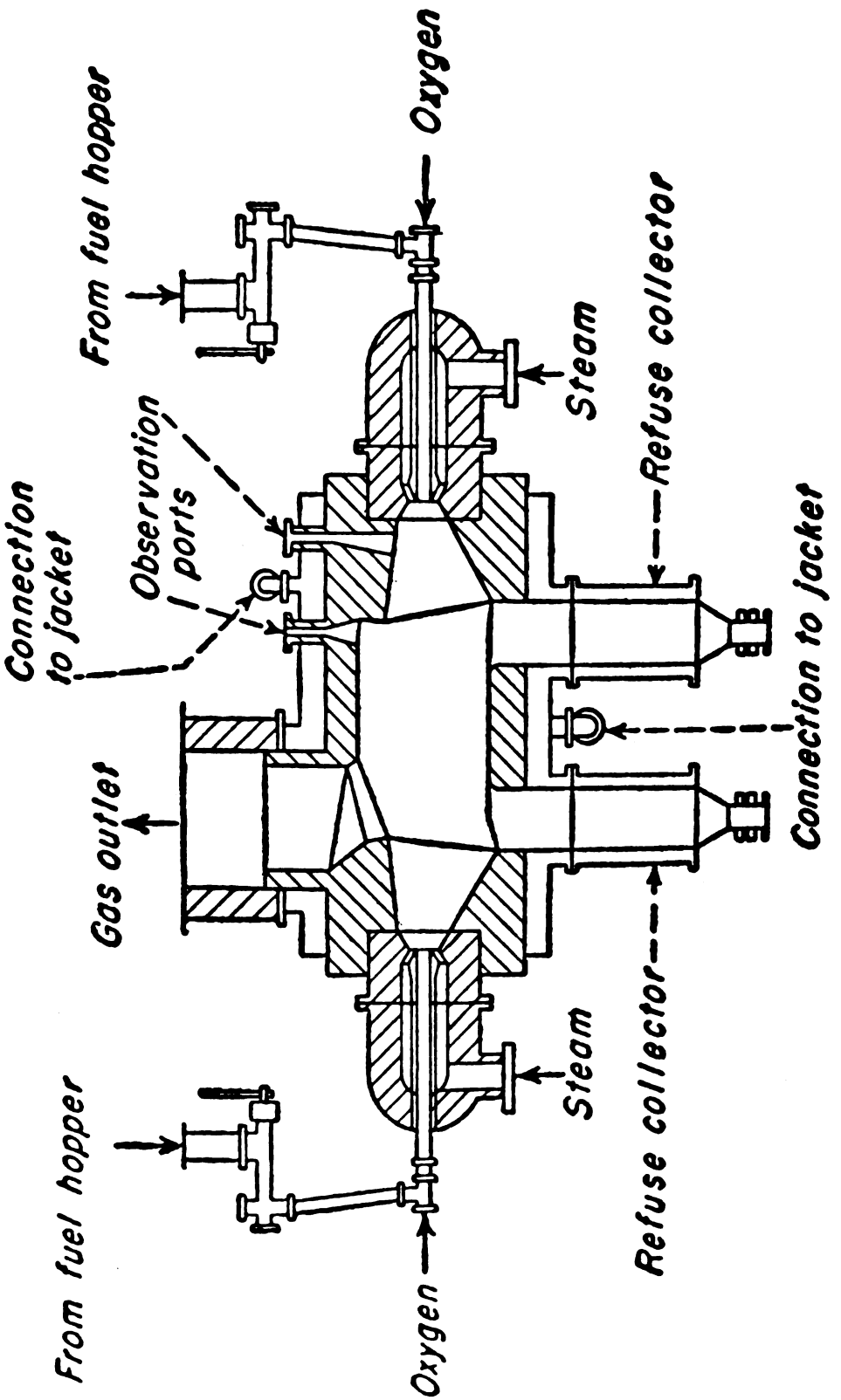

Figure 20. - Koppers pulverized atmospheric gasifier. See reference (22) in section 3.
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TABLE 36. - Typical performance data for Koppers gasifier, Bureau of Mines, Louisiana, Mo.

Rock Springs, Wyo., coal (typical analysis given below)		
Steam temperature	°F.	1,700
Gasification temperature	do.	2,480
Feed rates:		
Raw coal	lb./hr.	2,297
Oxygen - 95% pure	std. cu. ft./hr.	21,600
Steam	lb./hr.	1,800
Oxygen (100%) to dry coal ratio	std. cu. ft./lb.	9.0
Steam to dry coal ratio	lb./lb.	0.8
Steam decomposed	percent	16
Products:		
Total gas	std. cu. ft./hr.	72,500
(H_2 + CO)	do.	59,240
Dry coal	lb./M std. cu. ft. of (H_2+CO)	38.8
Oxygen	std. cu. ft./M std. cu. ft. of (H_2+CO)	349
Steam	lb./M std. cu. ft. of (H_2+CO)	30.4
Carbon gasified	percent	83.4

Typical analysis of Rock Springs, Wyo., coal (moisture-free basis)

Proximate, percent			Ultimate, percent					
Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	B.t.u.
41.6	51.8	6.6	4.8	72.8	1.5	13.2	1.1	12,960

Approximate moisture of raw coal, 10 to 14 weight-percent.

Recent data on operation of the Morgantown, W. Va., atmospheric gasifier charging a subbituminous C coal from Lake De Smet, Wyo., are shown in table 37. This coal is the lowest-rank coal gasified to date in the Morgantown unit and is only slightly higher in rank than lignite.

Recent announcements (10, 22) have reported that the Du Pont Corp., in cooperation with Babcock & Wilcox, has developed a very large pilot plant for the production of synthesis gas at their Belle, W. Va., works. It appears, from the information released, that many of its features parallel the design of the Morgantown, W. Va., atmospheric gasifier.

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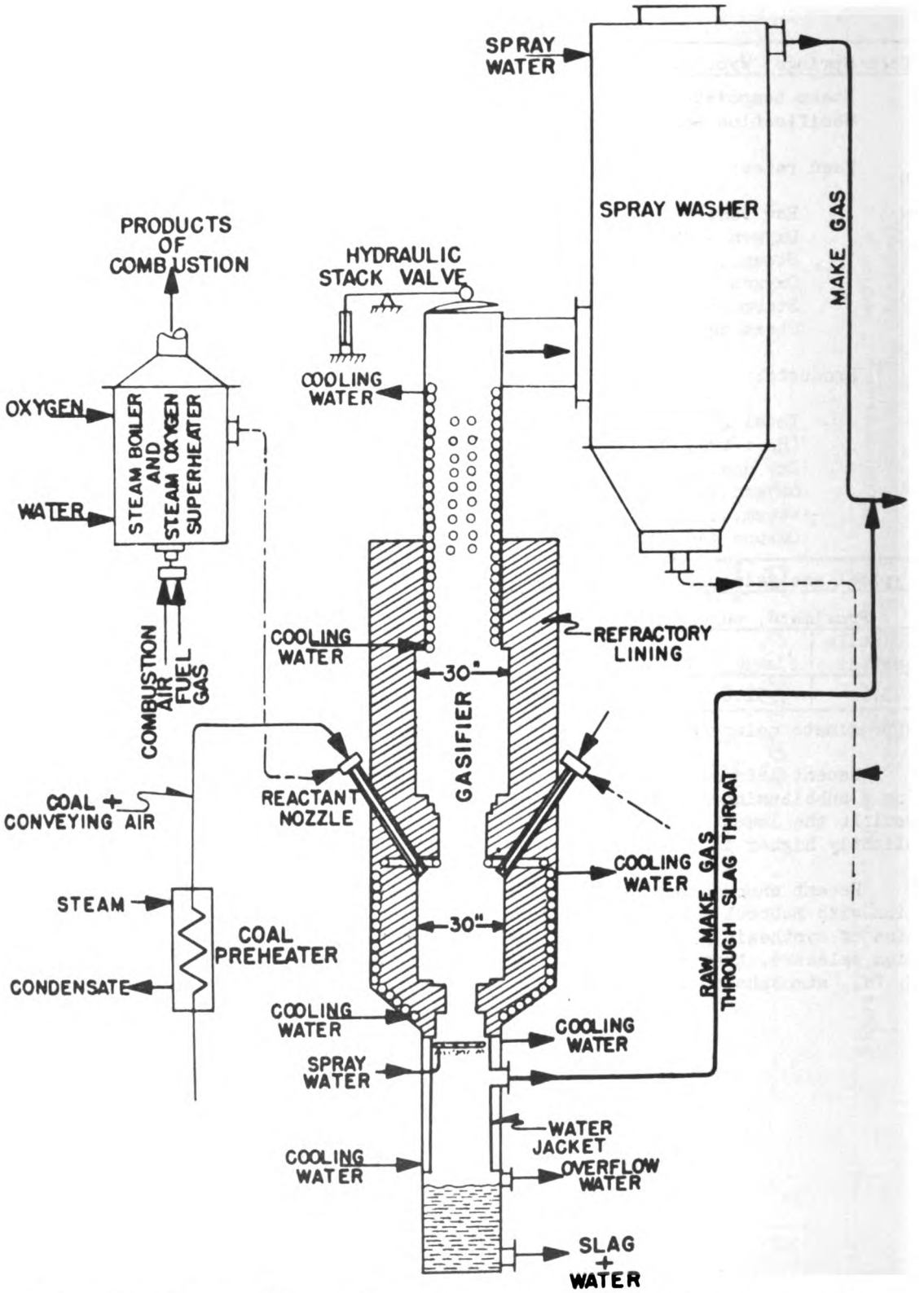

Figure 21. - Bureau of Mines pulverized atmospheric gasifier, Morgantown, W. Va.

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TABLE 37. - Results using Morgantown atmospheric-pressure gasifier with dried subbituminous C Lake de Smet coal[1]

Run No.	Coal rate, lb./hr.	Process steam, lb./lb. raw coal	Process oxygen, std. cu. ft./lb. coal	Carbon in coal gasified, percent	Material requirements/M std.cu. ft. of (CO + H_2)			Ash in slag at slag tap, percent of ash input	Ash in carbonaceous residue out top of gasifier, percent of ash input
					Coal, as charged, lb.	Process oxygen, std. cu. ft.	Process steam, lb.		
52A	531	0.12	8.58	98.5	45.3	389	5.5	73.2	32.7
52C	531	.12	7.51	94.2	43.8	329	5.4	19.6	49.7
52B	531	.12	6.95	93.1	43.2	300	5.3	2.9	54.2
53A	500	.13	9.17	95.4	45.2	414	5.9	67.3	27.0
53B	500	.13	7.98	99.4	40.9	326	5.3	12.9	40.0
53C	500	.13	6.98	96.5	41.8	292	5.4	17.4	63.8
54A	545	.073	7.71	96.2	42.7	329	3.1	23.3	56.3
54B	545	.073	6.29	86.7	45.9	289	3.4	.3	55.4
54C	545	.073	5.91	83.2	48.8	288	3.6	.3	71.7
54D	545	.073	5.49	78.8	51.9	285	3.8	.0	62.3
54E	545	.073	4.95	72.0	58.5	290	4.3	2.7	77.7
54J	613	.065	7.81	98.0	42.7	334	2.8	86.2	26.2
54I	613	.065	7.41	96.4	41.8	310	2.7	43.8	48.5
54H	613	.065	6.88	92.1	44.7	308	2.9	26.2	58.7
54G	613	.065	6.39	88.5	47.6	305	3.1	11.5	56.8
54F	613	.065	5.82	82.6	49.6	289	3.2	.5	60.0

Average analysis of Lake de Smet coal as charged in above experiments:

Run No.	Ultimate analysis, percent							B.t.u./lb.	
	Moisture	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Ash	Gross	Net
54	10.1	4.3	56.9	1.1	15.8	0.7	11.1	9,785	9,285
52, 53	7.6	4.1	58.5	1.2	16.2	.9	11.5	9,935	9,474

1/ Unpublished data, Morgantown, W. Va.

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Bureau of Mines Pressure Gasifier, Morgantown, W. Va.

A pressure gasifier operating on powdered coal at 30 atmospheres pressure has been developed at the Morgantown, W. Va., station of the Bureau of Mines. A sketch of the gasification unit is shown in figure 22. In this process coal is pulverized to 70 percent through a 200-mesh screen. It is conveyed by a fluidized coal feeder to the gasifier. The gasifier has an overall length of 12 feet and is 30 inches i.d. A water coil is used to cool the outside metal walls of the pressure vessel over most of the length of the gasifier. The gasification section, which occupies the upper 3 feet 10 inches of the vertical cylinder, is refractory lined. This section is 8 inches i.d. Below the gasification section a spray ring is installed through which pass the products of gasification, and the bottom of the unit forms a water-filled slag pot. Steam for the unit is heated to 1,000° F. before being injected, but the oxygen is not preheated. Coal, steam, and oxygen are mixed in a special burner, which creates a high degree of turbulence in the entering reactants. This nozzle is set axially at the top of the gasifier tube. The gasification products and the slag formed flow down out of the gasification section and pass through the water spray ring. Gas is withdrawn just below this ring, and the slag, broken into fragments by water quenching, falls into the slag pot.

Development on this unit has been described in various publications (3, 5, 6, 19, 30). After certain operating difficulties in the original equipment have been solved, the general operation has proceeded smoothly. In a recent report (30) it was stated that the expected heat loss through the gasifier wall will be low in commercial-scale models because of the reduced surface-to-volume ratio in larger units. Thus it might be possible to use water-cooled refractory walls or possibly bare water-cooled interior walls. Such a procedure would be attractive economically with respect to cost of maintenance of these surfaces.

In table 38 operating data are presented for the Morgantown, W. Va., pressure gasifier in comparison with the atmospheric-pressure gasifier at the same station. The effect of pressure on the gasification process within the range 100-450 p.s.i.g. is shown.

Lurgi Pressure-Gasification Process

In the Lurgi process, the use of high pressure and oxygen are combined with a fixed bed of lump fuel and dry removal of the ash. This is one of the oldest satisfactory synthesis-gas producers in operation today. Commercial-size units have been installed in Germany since 1936.

The standard Lurgi generator, as installed in Germany, was approximately 22.3 feet tall, 10 feet o.d., and 9 feet i.d. Sketch of a typical Lurgi unit is presented in figure 23 (21). The outer shell was water cooled with a water jacket, and the inside wall was protected by a brick lining down to within 3 feet of the rotating grate, which supports the fuel bed. The lining was installed primarily to prevent generation of excessive amounts of steam in the jacket. The generator was operated at approximately 20 atmospheres pressure. Fuel was fed periodically to a coal lock hopper device from which the generator could be fed continuously. A gas disengaging space at the top of the generator was kept free of fuel with a skirt, which provided a base for a mechanical scraper to remove accumulations of pitch and carbon.

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TABLE 38. - Comparative typical results of Morgantown pressure and atmospheric gasifiers

	Pressure gasifier				Atmospheric pressure			
Run No.	14	17	23	30	21	31	29	18
Gasifier pressure, p.s.i.g.	100	250	300	450	atmos.	atmos.	atmos.	atmos.
Duration of run, hr.	10.0	7.2	5.2	4.0	7.00	6.50	10.75	2.50
Raw coal rate, lb./hr.	463	588	869	1,120	355	407	514	598
Process steam inlet temperature, °F.	931	1,132	660	627	618	563	572	594
Process-oxygen inlet temperature, do.	60	58	660	627	618	563	572	594
Coal inlet temperature, do.	327	310	315	246	300	304	285	287
Oxygen input per pound coal, std. cu. ft.	9.22	9.35	8.83	9.84	9.05	8.33	8.28	7.83
Steam input per pound coal, lb.	0.30	0.28	0.28	0.33	0.79	0.39	0.43	0.56
Product gas analysis (corrected for inert gas introduced with coal in both cases and at gasifier sight glass in the case of pressure gasifier), percent:								
CO_2	7.1	7.9	8.5	10.4	17.4	12.7	13.0	14.5
Illuminants	.5	.7	.6	.5	.4	.5	.7	.4
H_2	34.4	33.9	34.4	32.9	39.5	36.5	37.4	39.1
CO	55.4	54.9	53.6	53.4	40.5	49.1	47.7	42.6
CH_4	.4	.5	.6	.7	.4	.4	.4	.5
(H_2 + CO), std. cu. ft./hr.	12,870	16,120	23,160	31,180	9,060	10,480	12,570	13,720
Total carbon gasified, percent	87.8	87.9	87.4	92.4	84.6	83.4	80.2	73.0
Coal required per M cu. ft. (H_2 + CO), lb.	36.0	36.5	37.5	35.9	39.2	38.8	41.0	43.6
Oxygen required per M cu. ft. (H_2 + CO), std. cu. ft.	333	341	331	352	355	323	340	341
Process steam input per M cu. ft. (H_2 + CO), lb.	10.9	10.2	10.5	11.8	30.9	15.3	17.6	24.3
Coal throughput/(hr.) (cu. ft. volume), do.	117	409	583	757	8.1	9.3	12.8	13.5

The tests listed above were run on the same coal (Sewickley-bed coal from Monongalia County, W. Va.).

A typical analysis, not from a specific sample, of this coal is as follows:

Coal analysis, as-fired basis, percent

Proximate		Ultimate	
Moisture	1.5	H_2	5.0
Volatile matter	34.5	C	70.0
Fixed carbon	50.5	N_2	1.5
Ash	13.5	O_2	7.5
		S	2.5
		Ash	13.5

Calorific value, B.t.u./lb.	
Gross	12,610
Net	12,120

Ash fusibility	Temperature, °F.
Initial deformation	2,171
Softening	2,248
Fluid	2,329

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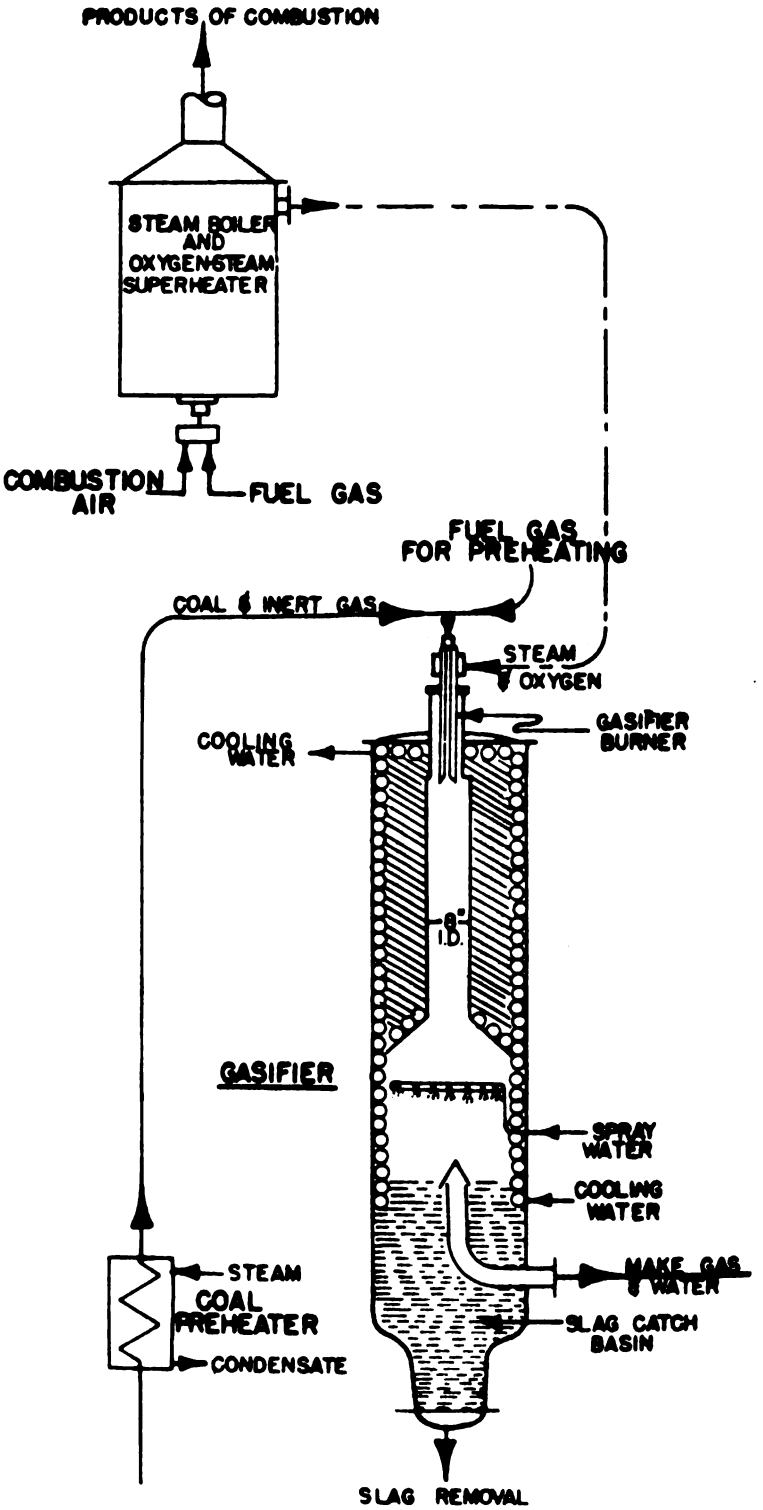

Figure 22. - Bureau of Mines pulverized pressure gasifier, Morgantown, W. Va.

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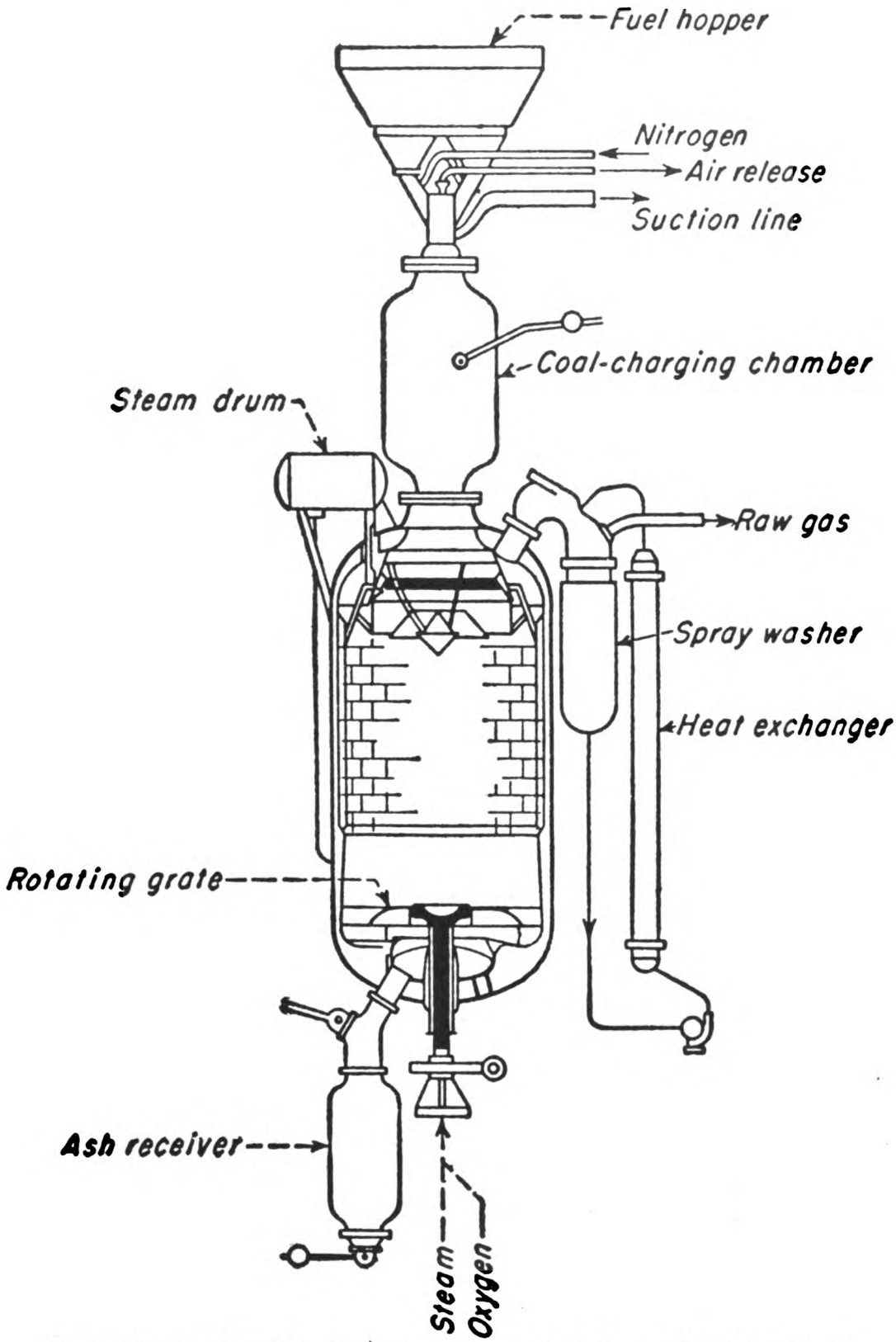

Figure 23. - Lurgi fixed bed pressure gasifier. See reference (22) in section 3.
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A rotating grate with attached plows was used to remove the ash from the fuel bed continuously and discharge it to an ash receiver below. Steam and oxygen were admitted through the hollow grate shaft into the reaction zone. Since the ash was removed dry, it was necessary to maintain a temperature below the ash-fusion temperature in the fuel bed. In the German plants the practice was to maintain the bed temperature below 2,100° F. The German brown coal being used had an ash-softening temperature of 2,400° to 2,700° F. (21).

Several things about the Lurgi unit are distinctive to the process. It is one of the few pressure units in which lump coal is utilized as a feed. In addition, the gas produced contains a reasonably large percentage of methane. This is not always an advantage; methane may be worthwhile to increase the gas heating value but is not desirable for most synthesis requirements; however, it is a definite advantage if high-B.t.u. gas is desired for utility distribution.

The Bureau of Mines has carried out some work at Pittsburgh on gasification of char from higher rank coals in a small experimental Lurgi generator, 13.5 inch i.d. (13). High gasmaking capacities were obtained in this unit, up to 7,250 cubic feet per square foot of grate area per hour, compared to rates in the range of 2,000 cubic feet per square foot per hour in conventional German practice. Methane content of the product gas was lower than in conventional German practice. It is suggested that methane content could be increased, if desired, by increasing bed height. The total height of the experimental generator was only 5.5 feet, versus 22.3 feet total height for the conventional Lurgi unit.

Typical operating data for gasification of char in the Bureau of Mines experimental unit are presented in table 39 (13).

Texaco Pressure-Gasification Process

In the Texas Co. coal-gasification pilot plant at Montebello, Calif., work has been in progress using a pulverized coal slurry for the base feed, oxygen for internal heating, and pressure (15). A process flowsheet is shown in figure 24.

The fuel is prepared by grinding it in a wet mill and mixing it with water in a conventional thickener to a ratio of 40 to 60 percent coal. This ratio depends on the particle size and density of the coal. From the thickener, the slurry is pumped through a heater under several hundred pounds pressure and raised to approximately 1,000° F. The heated mixture of steam and coal enters the top of the reaction chamber either axially or at a tangential angle near the top of the chamber. Oxygen, which may or may not be heated, enters the chamber near the feed nozzle but in such a manner as not to impinge upon the side of the reaction vessel. The amount of steam entering the process is regulated by installing a cyclone separator or settling drum after the preheater and withdrawing any excess. The temperature within the vertical cylindrical reactor is sufficient to liquefy the ash. The molten ash flows through a restricted opening below the reactor and falls into a reservoir of cold water. The resultant thermal shock disintegrates the particles, and they are removed as a finely divided solid suspended in the water. The gas is run through a waste-heat boiler to recover the sensible heat. It is reported that the complete range of coals from lignite to anthracite has been used, with a percentage gasification up to 95 percent. However, up to the present, detailed data on operation of this pilot plant have not been published.

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TABLE 39. - Test results of Lurgi pilot generator, Bureau of Mines, Pittsburgh, Pa.

Test No.	85A	85B	86	90	91	91a	91b	92
Fuel:								
Kind	Char	Char	Char	Char	Char	Char	Char	1/Char
Rate, lb./hr.	98	110	114	146	98	98	98	177
Steam:								
Lb./hr.	203	240	241	352	261	261	261	499
Lb./100 lb. fuel	212	229	211	241	267	267	267	282
Lb./1,000 cu. ft. gas	54	54	55	59	65	65	65	79
Oxygen, cu. ft./M cu. ft. ($CO + H_2$)	256	236	235	226	228	234	233	208
Steam decomposition, percent	38.3	39.6	41.9	40.2	35.8	35.8	35.8	33.6
Gas production of generator area:								
Cu. ft./sq. ft.	3,740	4,411	4,401	6,017	4,029	4,029	4,029	7,246
Cu. ft./ton of fuel	78,300	80,100	79,200	83,600	82,500	82,500	82,500	82,100
Gas analysis, percent:								
CO_2	26.8	26.8	26.8	28.6	28.3	29.0	27.7	29.2
Illuminants	.5	.4	.5	.1	.4	.4	.2	.2
H_2S	.4	.4	.4	.2	.2	.2	.2	.2
O_2				.3	.4	.4	.4	.2
H_2	41.1	41.2	41.4	40.2	39.5	39.8	40.1	41.4
CO	20.5	21.4	19.8	20.1	20.3	18.2	18.4	19.8
CH_4	8.7	7.9	9.0	7.1	8.6	9.3	8.4	6.4
C_2H_6	1.3	1.1	1.3	1.0	0.4	0.6	1.4	0.7
N_2	0.7	0.8	1.0	2.4	1.9	2.1	3.2	1.9
Ratio, H_2:CO	2.0	1.9	2.09	2.0	1.95	2.19	2.18	2.09
Calorific value:								
Raw gas	321	311	320	289	295	300	304	281
Washed to 2.5 percent CO_2	432	419	425	393	402	412	409	386
Superheater temperature, °C.	212	212	315	360	404	404	404	420
Gasification pressure, p.s.i.	300	300	300	300	300	375	405	300

The fuel used in the above test was char resulting from the carbonization of Pittsburgh seam coal (West Virginia), Jamison mine, No. 368. The proximate analysis of the char is as follows:

Volatile matter.. 20.9 percent Fixed carbon..... 68.4 percent Ash.... 10.7 percent

1/ Char sized 3/4 by 1/8 inch.

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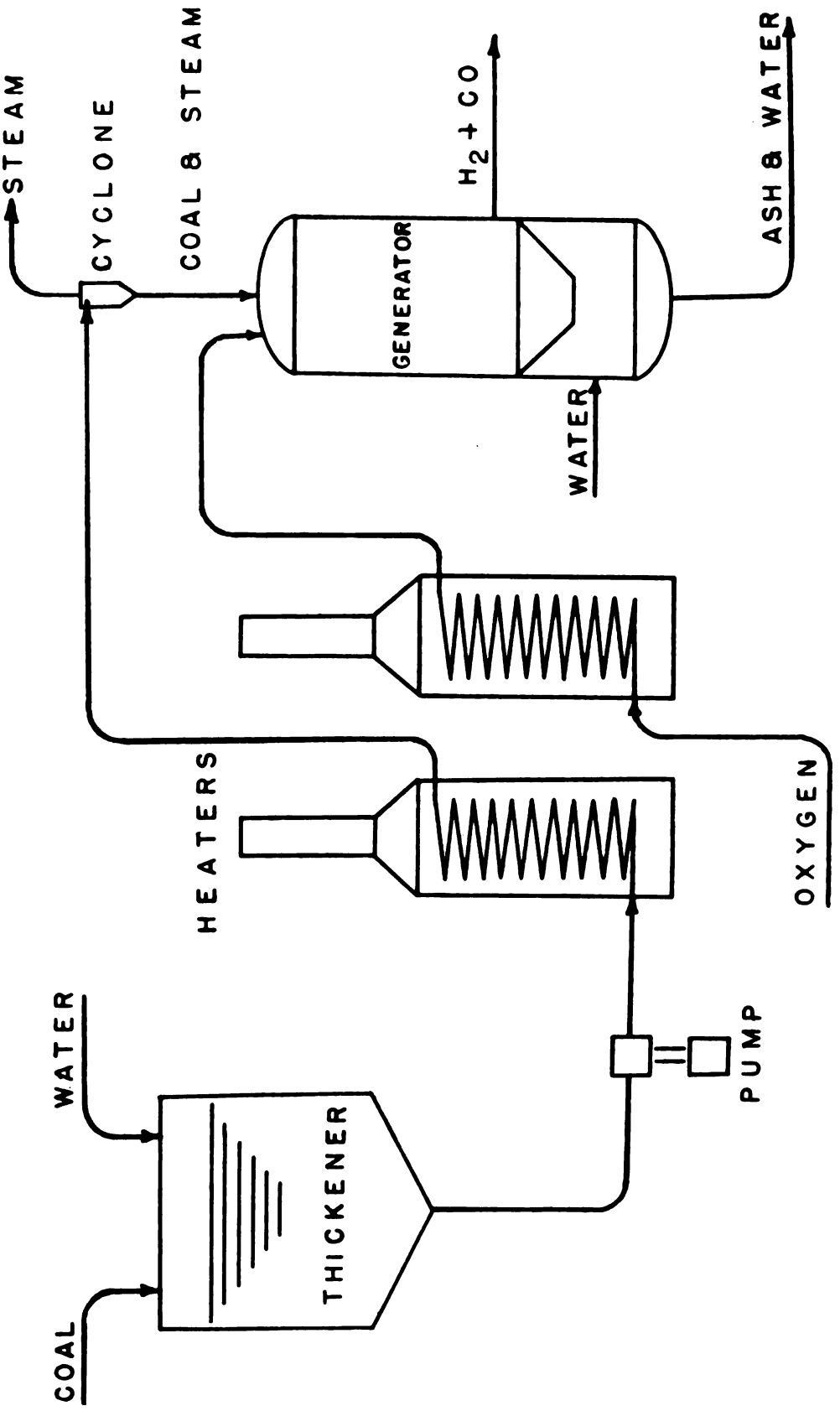

Figure 24. - Texas Co. pulverized pressure gasifier. See reference (16) in section 3.
(By permission of Am. Inst. Min. Met. Eng.)

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General Discussion of Operating Features

Before the individual gasification processes are summarized, it may be worthwhile to point out that there are general advantages and disadvantages, which are true of the majority of the processes utilizing various operation design features. The following pages summarize the main advantages and disadvantages of these features without distinction as to any individual gasification process. It should be kept in mind that any specific advantage or disadvantage may not apply to a particular process that falls in a group but generally is true of the group as a whole.

Pulverized Coal

1. Versatility. Gasification of pulverized coal, where the fuel is gasified while suspended, is more readily adaptable to both caking and noncaking coals than is gasification of lump fuel in fixed beds.

2. Contact time. The contact time required in pulverized operation is normally very short because of a large surface area available for reaction.

3. Slurry operation. Pulverized coal in slurry has the distinct advantage of simplifying the charging of the coal to the gasifier continuously while under higher pressures. Charging lump fuel against high pressure is more difficult.

4. Cost of pulverizing. Gasification of coarse-size coals requires only the breaking and sizing of comparatively large fractions of the coal. Gasification of pulverized coal requires finely divided coal, which adds to gasification cost.

5. Ash in gas. A larger percentage of the ash is carried by the gas stream in pulverized processes than in processes having coarse fuels in fixed beds. This complicates the problem of securing clean gases.

6. Countercurrent versus concurrent flow. In most pulverized-coal gasification systems the gas and coal particle move concurrently. This has the effect of removing the particle from the reaction space after a very short contact time and, since the two move at approximately the same rate of speed, of reducing any scrubbing action of the gas on the surface of the coal particle. Since the gas leaves the process at a high temperature in pulverized systems, the heat economy associated with countercurrent flow of product and reactants is not present inherently in this type of operation. In concurrent flow, the concentration of the reactants, carbon and steam, decreases continuously toward the gas outlet. For this reason complete conversion of the carbon may be difficult to achieve in units of economically feasible size.

7. Refractory service. When pulverized coal is used with internal heating, the high heat-release rates have created problems in maintaining the surrounding refractory walls.

Pressure Gasification

1. Capacity. Higher pressures increase the rate of throughput per unit volume while maintaining a high rate of gasification.

2. Many of the synthesis uses to which the product gas can be put, such as the manufacture of synthetic fuels, require gas at elevated pressures. In this case, no further compression of the gas is required (18).

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3. Scrubbing. For some purposes, it is possible in pressure operation to remove enough of the attendant CO_2 and H_2S by water scrubbing. The following table lists gas composition before and after scrubbing at 20 atmospheres (20, p. 1631).

	Gas analysis, percent	
	Before scrubbing	After scrubbing
$CO_2 + H_2S$	30.6	3.0
Illuminants	.6	.5
O_2	.1	.1
CO	16.5	22.8
H_2	34.0	48.7
CH_4	16.3	22.6
N_2	1.9	2.3

4. Design. The use of pressure requires reaction vessels and piping of heavy construction. This complicates the design of pressure-gasification equipment.

Internal and External Heating

1. Heat availability. In an internally heated unit, intimate contact between the source of the heat and the reactants allows uniform and rapid assimilation of the heat. In the externally heated unit, the heat is supplied through a wall, which means that only a portion of the reactants are in direct contact with the heat source at any particular moment. Therefore, higher capacities per unit volume are possible with internal heating.

2. Heat loss. Externally heated units are subject to heat loss from the comparatively large exposed surfaces. In internally heated pulverized gasification, the advantage of low external losses is offset by the high temperatures of the product gas, which must be utilized to provide good thermal efficiencies.

3. Heat source. External heating makes it possible to use cheaper fuels for heating in the form of producer gas, products of combustion, or other similar low-cost source of supply, since there is no contact of the heating gas and the product gas. In internal heating, a supply of reasonably pure oxygen is needed to eliminate nitrogen dilution. The cost of oxygen may be a significant item in the cost of gas produced by internal heating methods.

4. Preheated gases or preheated steam. To avoid using oxygen, preheated gases and steam have been used for internal heating. This requires the use of either large volumes of gas or steam or very high temperatures that are difficult and expensive to secure.

The figures presented in table 40 indicate the relative oxygen and steam requirements for the various processes and the relative capacities of the units. Not all of the gasification units were operating at maximum capacity at the time these tests were made. However, the figures are indicative of the order of magnitude and are useful for comparison.

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TABLE 40. - Capacity figures for various gasification processes[1/]

Type	Fuel tested	Capacity			Oxygen used	Oxygen required cu. ft. /M cu.ft. (H_2+CO)	Pressure p.s.i.g.	Carbon gasified percent	Steam added, lb/M cu. ft.(H_2+CO)
		Cu. ft. (H_2+CO)/hr.	Cu. ft. (H_2+CO)/(Sq. ft. grate area)(hr.)	Cu. ft. (H_2+CO)/(cu. ft. reaction space)(hr.)					
Grand Forks, externally heated	Dried lignite, lump	13,400	-	260	No	None	Atmos.	79	35
Battelle, externally heated	Dried lignite, pulverized	450-980	-	135-300	No	do.	do.	65-80	40-50
Koppers	Subbituminous, pulverized	59,250	-	200	Yes	350	do.	83.5	30
Morgantown atmospheric	Bituminous, pulverized	13,000	-	395	Yes	320-350	do.	73-85	15-30
	Subbituminous, pulverized	14,500	-	440	Yes	270-400	do.	76-97	
Morgantown pressure	Bituminous, pulverized	31,000	-	21,000	Yes	330-350	450	90	10-12
Lurgi	Bituminous, char, lump	4,200-5,400	4,200-5,400	780-1,000	Yes	200-255	300-400	-	90-130

1/ These figures are from data presented in this section for experimental units. They are not necessarily representative of maximum production or optimum conditions.

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Many of the data presented in table 40 have been based on the use of higher rank coals because of the lack of specific information on use of lignite in these particular processes. Lignite could be used in all the processes, however, and in some instances would have a considerable advantage. The noncoking, low-rank coals have a specific advantage for use in fixed-bed gasification, the process providing maximum heat economy and lowest oxygen requirement. For fixed-bed pressure gasification, pretreatment would be required before coals having even slight coking tendency could be used. In slagging processes, the relatively low ash fusion temperature of North Dakota lignite would lower the operating-temperature level required to keep slag molten and reduce difficulties attendant on high-temperature operation. Data for fine-particle gasification of low-rank coal, close to lignite in rank, indicate that gasification capacities equal to or higher than those for higher rank coals can be obtained with comparable oxygen requirement.2/

Steam Requirements

As would be anticipated, the lowest steam requirements in pound per 1,000 cubic feet H_2 + CO are realized in the pulverized, and particularly in the pulverized-plus-pressure gasification processes where steam requirements run from 12 to 30 pounds. The externally heated units run somewhat higher than this, at 30 to 45 pounds, and the highest demands are made by the Lurgi process. In the Lurgi process, one of the main functions of the steam is to reduce the temperature of the fuel bed to maintain it below the fusion point of the ash.

Oxygen Requirements

In oxygen requirements, the reverse of steam consumption is true, with the Lurgi process using considerably less oxygen than any of the other processes employing oxygen. Since the cost of the oxygen may be a large increment in the cost of the gas, this is a very important consideration. For example, the lack of oxygen requirements is an advantage of the externally heated retort.

Capacities

The capacity figures list a wide range of capacities per unit of reaction space. These may be grouped as follows: (1) Gasifiers without oxygen and at atmospheric pressures, 150 to 300 cubic feet (H_2 + CO) per hour per cubic foot reaction space; (2) Lurgi gasifier with coarse fuel, oxygen, and pressure, 780 to 1,000 cubic feet; and (3) Morgantown pressure gasifier with pulverized fuel, pressure, and oxygen, 21,000 cubic feet. The capacity of each process must be balanced against the relative heat economy and the cost of steam and oxygen required in its operation.

Future and Present Uses of Synthesis Gas

Synthesis gas is a mixture of hydrogen and carbon monoxide. As such it represents a midpoint from raw materials to product in a variety of chemical synthesis operations. In the past, the source of this gas has been the gasification of coke and, of late years, natural gas (31). However, as the supply of natural gas is diminished, the use of direct gasification of the coal supplies will become increasingly important (10). A. R. Powell (26) has presented a rather complete outline of the present and future uses of synthesis gases by industry. In this paper the chemical reactions to be utilized and being utilized are broken down to three groups:

2/ Unpublished data, Morgantown, W. Va.

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(1) The reaction between hydrogen and carbon monoxide with or without the addition of other reactants; (2) the reaction between hydrogen and other reactants; and (3) the reaction between carbon monoxide and other reactants. Listed among those in group (1) are the oxygenated compounds, namely the acids, ketones, alcohols, aldehydes, and esters, as well as hydrocarbons for use as synthetic liquid fuels. At the present time, the largest consumer group (2) is the synthetic ammonia industry. The use of hydrogen for ammonia synthesis, began in 1913, has steadily increased since, and promises to continue to grow in importance. Also included in this group are such uses as the hydrogenation of oils and fats to produce such items as margarine, hydrogenation of coal to produce chemicals and fuels, hydrogenation of organic chemicals and oils, and production of hydrochloric acid (14, 28). Group (3) is at present less important than the other two. However, use has been made of carbon monoxide alone in the metallurgical field, and the use of the synthesis gas in this manner is expected to increase.

Producer Gas

Producer gas is obtained by incomplete combustion of solid fuel with air, usually accompanied by simultaneous addition and partial reduction of steam. The resulting gas has a high nitrogen content and a relatively low heating value. Typical heating value is only about 150 B.t.u. per cubic foot; however, this simple and efficient process represents, in general, the cheapest available means for converting solid fuels to a fuel-gas product.

Because of its low heating value, producer gas is not suitable for utility distribution and is normally used at or near the point of production. The use of producer gas reached its peak in the United States about 40 years ago. By 1910, it was being used extensively in such fields as fuel for internal-combustion engines, in the manufacture of steel and in annealing, drying, evaporating, heating molds, brick kilns, cement kilns, and in ore-roasting furnaces. These uses have been steadily diminished because of expansion in use of competitive fuels, particularly natural gas and petroleum products.

Since producer gas is still the cheapest fuel gas that can be obtained from solid fuels, it retains some immediate and long-term importance for industrial use. In addition to conventional uses, conversion to producer gas may eventually prove to be the most practical and economical method for utilizing coal in the gas turbine as development proceeds in this field (2).

There has been no recent development on gas producers using lignite as fuel in the United States. Older data obtained by the Bureau of Mines indicate that lignite can be gasified successfully in conventional updraft gas producers, although the operating capacities achieved were relatively low (17). Typical operating data are presented in table 41.

In table 42, capacity data for German producers of conventional design, using brown coal and brown-coal briquets, are presented for comparison (1, p. 83).

Most of the more recent development work on gasification of low-rank coals to make producer gas has been carried out in Europe, where producer gas is more important economically at this time than it is in the United States. Information on these developments is reported in the section on European practice.

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TABLE 41. - Performance data for updraft producers using lignite

Plant No.	4	11
Proximate analysis, percent:		
Moisture	29.20	27.21
Volatile matter	36.92	47.55
Fixed carbon	27.02	17.50
Ash	6.86	8.21
Sulfur	0.58	0.44
Heating value as fired, B.t.u./lb.	7,442	7,073
Area of grate, sq. ft.	19.6	38.5
Fuel, lb./hr.	1/250	2/570
Fuel, lb./(sq. ft.)(hr.)	12.8	14.8
Approximate gas made, cu. ft./(hr.)(sq. ft. grate area)	400	450
Depth of bed, ft.	2.0	1.5
Typical gas analysis:		
Component, percent:		
CO	21.0	
CH_4	2.2	
CO_2	12.4	
C_2H_6	0.4	
O_2	0.0	
H_2	18.5	
B.t.u./cu. ft. calc	155	

1/ Charge: 500 pounds every 2 hours.
2/ Charge: 190 pounds every 20 minutes.

TABLE 42. - Standard capacity for German producers

Fuel used	Stationary grate, natural draft, capacity, lb./(sq.ft.)(hr.)	Stationary grate, forced draft, capacity, lb./(sq.ft.)(hr.)	Rotating grate, forced draft, capacity, lb./(sq.ft.)(hr.)
Brown-coal briquets	10.2-12.3	12.3-16.4	16.4-22.6
Brown coal, as mined	16.4-20.5	22.6	32.8-36.9

Note
For briquets: 1 lb. of briquets generates 41.3 std. cu. ft. of gas, moist, at 156 B.t.u./cu. ft.

For brown coal: 1 lb. of brown coal, as mined, generates 20.7 std. cu. ft. of gas, moist, at 114 B.t.u./cu. ft.

Typical ultimate analysis of fuel, percent:

	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Brown-coal briquets	54.5	5.9	33.4	0.8	0.4	5.0
Brown coal, as mined	28.5	8.3	60.0	.4	.2	2.6

	Gross heating value, B.t.u./lb.	Moisture content, percent
Brown-coal briquets	9,200	15.0
Brown coal, as mined	4,750	55.8

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Bibliography

1. BRAUNKOHLEN-ANHALTSZAHLEN. 3 Ausgabe 1929, Neudruck mit Ergänzungen, February 1931, 160 pp.

2. BUCKLAND, B. O., HILLMAN, A. Y., JR., AND NELSON, H. W. Producer Gas for Gas Turbines. Gen. Elec. Rev., vol. 54, No. 12, Dec. 1951, pp. 12-26.

3. BUREAU OF MINES. Synthetic Liquid Fuels, Annual Report of the Secretary of the Interior for 1949, Part I-Oil From Coal. Rept. of Investigations 4651, 1950, 62 pp.

4. _____. Synthetic Liquid Fuels, Annual Report of the Secretary of the Interior for 1950, Part I-Oil From Coal. Rept. of Investigations 4770, 1951, 74 pp.

5. _____. Synthetic Liquid Fuels, Annual Report of the Secretary of the Interior for 1951, Part I-Oil From Coal. Rept. of Investigations 4865, 1952, 83 pp.

6. _____. Synthetic Liquid Fuels, Annual Report of the Secretary of the Interior for 1952, Part I-Oil From Coal. Rept. of Investigations 4942, 1953, 85 pp.

7. BURR, A. C., ELLMAN, R. C., HOEPPNER, J. J., HOLTZ, J. C., KAMPS, T. W., KUBE, W. R., ONGSTAD, O. C., AND OPPELT, W. H. Gasification of Lignite in a Commercial-Scale Pilot Plant - Progress Report, January 1949 to June 30, 1950. Bureau of Mines Rept. of Investigations 4997, 1953, 48 pp.

8. BURR, A. C., HOLTZ, J. C., KOTH, A. W., AND OPPELT, W. H. Gasification of Lignite in a Commercial-Scale Pilot Plant - Progress Report for 1947-48. Bureau of Mines Rept. of Investigations 4940, 1953, 28 pp.

9. BUSINESS WEEK. A Milestone of Chemicals? June 13, 1953, pp. 138-140.

10. CHEMICAL ENGINEERING. 1952 Outlook: Gas and Liquids From Coal. Vol. 59, No. 4, 1952, pp. 299-314.

11. CHETRICK, M. H. Thermal Requirements for the Gasification of Lignite in an Externally Heated Retort. Bureau of Mines Rept. of Investigations 4957, 1953, 7 pp.

12. _____. Undecomposed Steam in Lignite Gasification. Bureau of Mines Rept. of Investigations 4738, 1950, 11 pp.

13. COOPERMAN, J., DAVIS, J. D., SEYMOUR, W., AND RUCKES, W. L. Lurgi Process, Use for Complete Gasification of Coals with Steam and Oxygen Under Pressure. Bureau of Mines Bull. 498, 1951, 38 pp.

14. DONATH, E. E. Chemicals From Coal Hydrogenation. Symposium on Gasification and Liquefaction of Coal. AIME, New York, N. Y., 1953, pp. 15-27.

15. EASTMAN, D. Preliminary Report on Coal Gasification. Symposium on Gasification and Liquefaction of Coal. AIME, New York, N. Y , 1953, pp. 73-79.

16. FOSTER, J. H. Production of Water Gas From Pulverized Coal. Ind. Eng. Chem., vol. 40, No. 4, 1948, pp. 586-592.

17. FERNALD, R. S. Operating Details of Gas Producers. Bureau of Mines Bull. 109, 1916, 74 pp.

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18. GUMZ, W. Gasification of Solid Fuels at Elevated Pressures. Ind. Eng. Chem., vol. 44, No. 5, 1952, pp. 1071-1073.

19. KASTENS, M. L., HIRST, L. L., AND DRESSLER, R. G. An American Fischer-Tropsch Plant. Ind. Eng. Chem., vol. 44, No. 3, 1952, pp. 450-466.

20. LOWRY, H. H. (editor). Chemistry of Coal Utilization. John Wiley & Sons, Inc., New York, N. Y., 1945, vol. 2, pp. 991-1868.

21. NEWMAN, L. L. Oxygen in the Production of Hydrogen or Synthesis Gas. Ind. Eng. Chem., vol. 40, No. 4, 1948, pp. 559-582.

22. OIL, PAINT AND DRUG REPORTER. Du Pont Synthesis Gases Unit to Use New Process. May 25, 1953, p. 5.

23. PARRY, V. F., GERNES, D. C., WAGNER, E. O., GOODMAN, J. B., AND KOTH, A. W. Gasification of Lignite and Subbituminous Coal, Progress Report for 1945-46. Bureau of Mines Rept. of Investigations 4128, 1947, 69 pp.

24. PARRY, V. F., GERNES, D. C. WAGNER, E. O., GOODMAN, J. B., KOTH, A. W., PATTY, W. L., AND YEAGER, E. C. Gasification of Lignite and Subbituminous Coals. Bureau of Mines Rept. of Investigations 3901, 1944, 59 pp.

25. PARRY, V. F., WAGNER, E. O., KOTH, A. W., AND GOODMAN, J. B. Gasification of Subbituminous Coal and Lignite in Externally Heated Retorts. Ind. Eng. Chem., vol. 40, No. 4, 1948, pp. 627-641.

26. POWELL, A. R. Relation of Coal Gasification to the Production of Chemicals. Symposium on Gasification and Liquefaction of Coal, Am. Inst. Min. and Met. Eng., New York, N. Y., 1953, pp. 196-206.

27. _____. Future Possibilities in Methods of Gas Manufacture. Am. Gas. Assoc., pres. at the 1947 Joint Production and Chemical Committee Conference, New York, N. Y., June 2-4, 1947, 28 pp.

28. SKINNER, L. C. Progress in Coal Hydrogenation. Symposium on Gasification and Liquefaction of Coal, Am. Inst. Min. and Met. Eng., New York, N. Y., 1953, pp. 1-14.

29. STRIMBECK, G. R., CORDINER, J. B., JR., BAKER, N. L., HOLDEN, J. H., PLANTS, K. D., AND SCHMIDT, L. D. Gasification of Pulverized Coal with Steam and Oxygen at Atmospheric Pressure. Bureau of Mines Rept. of Investigations 5030, 1954, 37 pp.

30. STRIMBECK, G. R., CORDINER, J. B., JR., TAYLOR, H. G., PLANTS, K. D., AND SCHMIDT, L. D. Progress Report on Operation of Pressure-Gasification Pilot Plant Utilizing Pulverized Coal and Oxygen. Bureau of Mines Rept. of Investigations 4971, 1953, 27 pp.

31. SULLIVAN, F. W. Fuel-Synthesis Byproducts as a Source of Chemicals. Chem. Eng. Prog., vol. 43, No. 12, 1947, pp. 13-17.

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4. HYDROGENATION OF LIGNITE

Introduction

The use of hydrogenation as a means of converting lignite to more valuable products, such as liquid fuels or chemicals, deserves consideration as a method of utilizing this important natural resource. The information available on direct hydrogenation of lignite may be roughly classified into (a) data from commercial plant operation and laboratory experiments in Germany, (b) results from bench-scale and laboratory investigation at the Bruceton Station of the Bureau of Mines, and (c) operating results from Bureau of Mines demonstration plant programs at Louisiana, Mo. In addition, literature data are available on hydrogenation of tars obtained by the carbonization of lignite. An excellent bibliography on hydrogenation has been prepared and contains abstracts of literature and patents to 1950 (8).[1/] It should be pointed out that the data available on industrial hydrogenation plant operation on German brown coal are not directly applicable to North Dakota or other American lignites, and therefore this information is only briefly summarized in this report, primarily to provide some background on plant design, process problems, and types of products. Considerably more information is presented on recent research developments that might provide some basis for rather speculative estimates of hydrogenation as a process tool in the future utilization of lignite.

Commercial Plant Operation

The process of hydrogenating coal to produce liquid fuels as practiced in Germany consists in pumping a mixture of about equal parts of dried powdered coal and recycle heavy oil, along with hydrogen, at about 200 to 700 atmospheres pressure into reactors maintained at 450° to 485° C. (liquid-phase hydrogenation). A small amount (0.1 to 1 percent by weight of the coal) of powdered catalyst is included in the coal-oil paste. During the reaction period of 1/2 to 3 hours, the coal-oil mixture is converted to a product oil (usually termed "middle oil") boiling below 325° C. and heavy oil, which is recycled to be mixed with coal and then fed to the plant. The middle oil is hydrogenated in one or more stages over fixed beds of catalyst particles and converted to gasoline. The process is described in greater detail by Gordon and a group of investigators (6). The ultimate analysis on a moisture- and ash-free basis of the coal utilized at the I.G. Farben Leuna Plant is given in table 43, together with ultimate analyses of various American lignites and coals.

TABLE 43. - Ultimate analysis of coals on moisture- and ash-free basis

	County	State or country	Ultimate analysis, weight-percent				
			Hydrogen	Carbon	Nitrogen	Sulfur	Oxygen
Brown coal	-	Germany	5.4	71.2	0.8	4.3	18.3
Velva	Ward	North Dakota	4.5	70.2	1.0	.2	24.1
Beulah	Mercer	do.	4.4	69.5	1.0	.9	24.2
Arkansas	Manning	Arkansas	7.1	71.8	1.1	.9	19.1
Washington	Lewis	Washington	5.5	68.0	1.4	1.1	24.0
Rock Springs	Sheridan	Wyoming	5.3	78.0	1.6	1.0	14.1
Bruceton	Allegheny	Pennsylvania	5.4	82.8	1.6	1.0	9.2

1/ Underlined numbers in parentheses refer to citations in the bibliography at the end of this section.

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The yields, based on moisture- and ash-free coal, obtained from this coal by liquid-phase hydrogenation, were as follows:

	Pounds per 100 pounds of m.a.f. coal
Gasoline plus middle oil <325° C.	50.0
Hydrocarbon gas	15.2
Oxides of carbon	10.6
Unconverted coal	1.5
Losses in solids removal	8.5
Water, ammonia, H_2S etc.	20.9
Hydrogen chemically absorbed	6.7

The middle oil was converted to gasoline by further hydrogenation, and the overall yields, based on m.a.f. coal, were as follows:

	Pounds per 100 pounds of m.a.f. coal
Motor gasoline	46.2
Hydrocarbon gases	19.3
Hydrogen chemically absorbed	9.1

The figures given for hydrogen consumption include only the hydrogen chemically combined, and additional hydrogen is required to make up for losses in gas streams and dissolved hydrogen in liquid products.

A comparison of brown coal and bituminous coal as hydrogenation plant feed is given in the Ministry of Fuel and Power report (2, p. 69). The brown coal produces about 25 percent less gasoline, causes higher oil losses in solids-removal processes owing to its higher ash content, requires more drying capacity owing to its higher as-mined moisture content, but requires about 15 percent less hydrogen. The effects of higher ash and moisture content in North Dakota lignites on hydrogenation yields have also been pointed out by Hirst and others (4), who estimate that 22,000 tons per day of run-of-mine lignite will be required for a plant producing 30,000 bbl. per day of liquid products, whereas only 11,800 tons per day of Rock Springs coal are needed. These values include coal required for hydrogen and power production. The costs of gasoline produced from these two coals are estimated to be almost the same if the lignite can be obtained for half of the cost of Rock Springs coal.

Laboratory Investigation

Considerable experimentation on hydrogenation of lignites in batch autoclaves and bench-scale hydrogenation units has been done at the Bruceton laboratories of the Bureau of Mines. This research has been directed toward the production of synthetic liquid fuels at lower cost through the development of improved catalysts, the study of process variables, the use of novel processing methods, and the utilization of byproducts.

The experimental procedures and methods of evaluation for batch autoclave hydrogenation have been given in detail (3, 7). Special precautions were exercised in the case of lignites, owing to the tendency of these coals to pick up or lose moisture. They were dried from a moisture content of 30 percent to an equilibrium moisture content of about 10 percent. Hydrogenation tests indicated no change in amenability to hydrogenation due to the drying process.

The product distribution obtained by the hydrogenation of several lignites and two bituminous coals in the absence of catalyst is given in table 44. The reaction time in all cases was 1 hour at 450° C. under an initial hydrogen pressure of 1,000

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p.s.i.g. These conditions are less severe than those used in commercial plants; and, although conversions are therefore lower, the differences between coals are more evident. The lignites tend to produce considerably more carbon dioxide and water, and the North Dakota lignites show rather low total oil yields. The total oil has been separated into an oil fraction, soluble in n-hexane, and an asphaltene fraction, insoluble in n-hexane. Each of these fractions has rather similar ultimate analyses even from various coals. The average analyses for these two fractions are given in table 45, with an average analysis for gasoline prepared from coal.

Tables 46 to 49 present data on the effects of various catalysts on the hydrogenation of lignites at 450° C. and 1,000 p.s.i.g. initial hydrogen pressure. Beulah and Velva lignites still show lower oil yields than those obtained with Washington and Arkansas lignite. The effect of molybdenum catalyst in decreasing carbon dioxide production appears to be due to the conversion of some carbon dioxide to methane and water. The effect of temperature of hydrogenation on the product distribution is shown in table 50 for Beulah lignite. It can be seen that above 450° C., at the initial hydrogen pressure of 1,000 p.s.i.g., the gas yield is increased at the expense of oil production. The effect of initial hydrogen pressure on distribution of products obtained by hydrogenation of Beulah lignite is given in table 51. The data indicate that increasing hydrogen pressure causes a decrease in the formation of carbon dioxide, benzene insolubles, and asphaltenes. The amount of hexane-soluble oil increases, with some indication, due to increased hydrocarbon-gas production, that a maximum will be observed at higher pressures. The effects of temperature and pressure, shown for one lignite, are quite similar for most coals.

The tests discussed above were all at conditions not normally used for industrial coal hydrogenation. As previously mentioned, these conditions were selected primarily to show the effects of various catalysts and type of coal. In table 52 product distributions obtained by the hydrogenation of Rock Springs coal and Velva lignite at 4,000 p.s.i.g. initial hydrogen pressure are presented. The reaction time was 1 hour and the temperature 450° C. for both coals. We can see that, in the absence of catalyst, both coals produce approximately equal amounts of total benzene-soluble oil. However, the Rock Springs coal is particularly amenable to catalysis, producing over 70 percent oil with both iron and molybdenum catalyst. Velva lignite does not respond too well to iron catalyst, and only a moderate increase in oil yield is obtained with molybdenum catalyst. The lower carbon content and higher oxygen content of Velva lignite reduce the maximum potential oil yield, compared with that possible from Rock Springs coal. However, the larger amount of benzene-insoluble matter obtained with Velva lignite might be reduced by developing special and more active catalysts. The ultimate analyses of the total benzene-soluble oils obtained with both coals are given in table 53. Although the oils obtained in the absence of catalyst are quite similar, the oils obtained from Rock Springs coal in the presence of iron and molybdenum contain more hydrogen and thus indicate a greater extent of hydrogenation.

The autoclave studies indicate that, in general, the North Dakota lignites, owing to a larger production of carbon dioxide, water, and gaseous hydrocarbons, produce less oil by hydrogenation than that observed for other coals. In addition, catalysts that show good results with most coals do not perform as well when used with these lignites, as evidenced by the higher production of benzene-insolubles observed. These results might be due to the higher ash content of these lignites and the alkalinity of the ash, which has been shown by others to be deleterious to some hydrogenation catalysts. Possibly some pretreatment of these lignites might improve their amenability to hydrogenation. For example, mild thermal treatment of lignites will tend to remove some of the oxygen content as carbon dioxide and water, the residue having the ultimate analysis of a bituminous coal. This residue might be more amenable to hydrogenation. In addition, development of specific catalysts for these lignites is a definite possibility.

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TABLE 44.—Product distribution, uncatalyzed hydrogenation for 1 hour reaction at 450°C. and 1000 p.s.i.g. initial H_2 pressure

Coals	Yield, % M.A.F.							H_2 consumed, MAF %
	Benzene insolubles	Benzene solubles			Gaseous hydrocarbons	CO_2	H_2O	
		Total oil	Asphaltene	n-Hexane solubles				
Velva lignite	44.81	22.10	7.7	14.40	13.20	11.3	11.20	2.58
Beulah lignite	51.12	19.24	8.06	11.18	11.15	10.35	10.32	2.36
Washington lignite	18.95	46.13	31.48	14.88	12.72	12.05	11.53	2.1
Arkansas lignite	13.80	50.40	23.60	26.80	14.60	12.00	13.72	4.46
Rock Springs coal	66.64	12.51	2.78	9.73	9.43	4.11	8.80	1.88
Bruceton coal	53.10	27.83	16.47	11.36	13.35	0.61	6.50	2.2

TABLE 45.—Ultimate compositions of asphaltene, n-hexane soluble oil and coal hydrogenation gasoline

	Percent				
	Hydrogen	Carbon	Nitrogen	Sulfur	Oxygen
Asphaltene	6.5	88.0	1.6	0.3	3.6
n-Hexane soluble oil	9.0	86.8	1.0	.2	3.0
Coal hydrogenation gasoline	11.8	88.0	.1	-	.1

TABLE 46.—Product distribution of uncatalyzed and catalyzed Arkansas lignite hydrogenation for 1 hour at 450°C. and initial hydrogen pressure of 1000 p.s.i.g.

Arkansas lignite	Yield, % M.A.F.							H_2 consumed, MAF %
	Benzene insolubles	Benzene solubles			Gaseous hydrocarbons	CO_2	H_2O	
		Total oil	Asphaltene	n-Hexane solubles				
Uncatalyzed	13.80	50.40	23.60	26.80	14.60	12.00	13.72	4.46
Neutralized 1/ and impregnated with 1% Mo	6.5	59.71	1.20	58.51	19.60	3.89	18.00	6.70
1% nickel, as $NiCl_2$	4.4	58.45	8.45	50.00	16.32	10.06	14.80	4.40
1% Sn + 0.5% NH_4Cl	7.2	55.25	17.75	37.50	18.75	8.30	14.50	4.75
1% Fe, as $FeSO_4$	10.00	53.75	27.50	28.25	16.25	10.80	10.0	3.90

1/ Neutralization (90%) was effected by adding 6.0 N. solution of H_2SO_4 to 1000 gm. of coal.

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TABLE 47.—Product distribution of uncatalyzed and catalyzed Washington lignite hydrogenation for 1 hour at 450°C. and initial hydrogen pressure of 1000 p.s.i.g.

Washington lignite	Yield, % M.A.F.							H_2 consumed, MAF %
	Benzene insolubles	Benzene solubles			Gaseous hydrocarbons	CO_2	H_2O	
		Total oil	Asphaltene	n-Hexane solubles				
Uncatalyzed	18.95	46.36	31.48	14.88	12.72	12.05	11.53	3.6
1% Mo (impregnated and neutralized)	7.30	53.06	1.00	52.06	15.07	5.61	16.58	6.9
1% Sn + 0.5% NH_4Cl	12.10	54.0	26.05	28.0	12.80	10.80	13.67	4.2

TABLE 48.—Product distribution of uncatalyzed and catalyzed Beulah lignite hydrogenation for 1 hour at 450°C. and initial hydrogen pressure of 1000 p.s.i.g.

Beulah lignite	Yield, % M. A. F.							H_2 consumed, MAF %
	Benzene insolubles	Benzene solubles			Gaseous hydrocarbons	CO_2	H_2O	
		Total oil	Asphaltene	n-Hexane solubles				
Uncatalyzed	51.12	19.24	8.06	11.18	11.15	10.35	10.32	2.58
Neutralized + 1% Ni ($NiSO_4$)	32.92	28.10	15.87	12.23	16.31	10.20	17.98	4.84
Neutralized + 1% Mo	18.34	46.54	12.80	33.74	14.40	6.70	19.52	5.80
Neutralized only	39.47	23.98	10.20	13.78	12.30	11.20	16.30	3.70
Un-neutralized:								
1% Mo	27.13	37.50	14.7	22.80	17.63	7.50	16.25	5.30
1% Fe(impregnated)	29.02	27.03	19.00	8.03	21.20	13.92	13.22	4.1
1% Sn($SnCl_2$)	25.00	44.84	22.68	22.16	11.21	12.83	13.43	4.73

TABLE 49.—Product distribution of uncatalyzed and catalyzed Velva lignite hydrogenation for 1 hour at 450°C. and initial hydrogen pressure of 1000 p.s.i.g.

Velva lignite	Yield, % M. A. F.							H_2 consumed, MAF %
	Benzene insolubles	Benzene solubles			Gaseous hydrocarbons	CO_2	H_2O	
		Total Oil	Asphaltene	n-Hexane solubles				
Uncatalyzed	44.8	22.10	7.7	14.40	13.20	11.3	11.20	22.10
1% Sn + 0.5% NH_4Cl	19.10	49.20	25.90	23.0	14.73	10.00	10.70	5.10

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TABLE 50.—Effect of temperature on product distribution of catalyzed Beulah lignite hydrogenation for 1 hour, using Mo catalyst and initial hydrogen pressure of 1000 p.s.i.g.

Beulah lignite Temperature °C.	Yield, % M. A. F.							H_2 consumed, MAF %
	Benzene insolubles	Benzene solubles			Gaseous hydrocarbons	CO_2	H_2O	
		Total oil	Asphaltene	n-Hexane solubles				
400	33.10	35.46	22.32	13.14	10.75	8.85	16.41	4.27
425	27.52	39.40	15.30	24.10	12.10	7.78	17.40	4.62
450	18.34	46.54	12.80	33.74	14.46	6.70	19.52	5.80
475	16.70	42.85	8.63	34.22	20.00	6.53	20.49	6.75

TABLE 51.—Effect of hydrogen pressure on product distribution of catalyzed Beulah lignite hydrogenation for 1 hour, using Mo catalyst at 450°C.

Beulah lignite Initial hydrogen pressure, p.s.i.g.	Yield, % M. A. F.							H_2 consumed, MAF %
	Benzene insolubles	Benzene solubles			Gaseous hydrocarbons	CO_2	H_2O	
		Total oil	Asphaltene	n-Hexane solubles				
500	34.71	31.91	11.91	20.00	13.20	8.90	16.70	4.50
1000	18.34	46.54	12.80	33.74	14.46	6.70	19.52	5.8
1750	14.80	48.75	5.35	43.40	17.31	4.67	20.73	6.85
2500	14.94	47.8	2.00	45.8	19.1	3.39	22.68	7.60

TABLE 52.—Product distribution of hydrogenated coals at 4000 p.s.i.g. initial hydrogen pressure 1 hour reaction at 450°C. using various catalysts

Coal	Catalyst	Yield, % M. A. F.							H_2 consumed, MAF %
		Benzene insolubles	Benzene solubles			Gaseous hydrocarbons	CO_2	H_2O	
			Total oil	Asphaltene	n-Hexane solubles				
Velva lignite	None	22.45	37.72	16.70	21.02	20.91	8.09	14.01	5.25
"	1% Fe as FeSO4	21.67	40.71	14.76	25.95	17.24	9.84	14.74	4.73
"	0.1% Mo	16.15	47.06	7.88	39.18	20.57	5.67	14.98	6.91
Rock Springs	None	40.42	39.70	20.77	18.93	7.32	4.78	10.82	3.04
"	1% Fe as FeSO4	4.23	73.15	45.48	27.67	14.79	2.60	9.29	5.30
"	0.1% Mo	2.70	74.61	5.88	68.73	13.57	.95	12.15	6.23

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TABLE 53. - Ultimate compositions of total oils obtained from hydrogenation of Velva lignite and Rock Springs coal

Coal	Catalyst	Percent				
		Hydrogen	Carbon	Nitrogen	Sulfur	Oxygen
Velva lignite	Uncatalyzed	8.40	87.50	0.95	0.2	2.95
Do.	1% Fe as $FeSO_4$	8.20	87.57	.76	.1	3.37
Do.	0.1% Mo as ammonium molybdate	8.82	87.47	.73	.44	2.55
Rock Springs	Uncatalyzed	8.54	87.38	1.13	.17	2.77
Do.	1% Fe as $FeSO_4$	8.73	86.77	1.19	.10	3.21
Do.	0.1% Mo as ammonium molybdate	9.15	87.23	.92	.1	2.60

Thus far the standard coal-hydrogenation processes for converting lignites to oil have been considered. In addition, some experimental work has been completed on the low-pressure hydrogenation of lignite in a bench-scale fluidized reactor. The techniques used in this work have been previously described (1). The objective of this process was to convert about half of the lignite into hydrocarbon gas and oil, with the residue char used as fuel or for hydrogen or synthesis-gas production. The data are summarized in table 54 for the preliminary work completed at this time on North Dakota, Arkansas and Texas lignites. Although the yields of oil and gas are quite satisfactory, the quality of the oils, particularly those obtained from the North Dakota lignites, are poor. In addition, considerable engineering development must be undertaken to eliminate problems of coal agglomeration, hydrocarbon-gas recovery, coal feeding, and product-oil handling. This type of processing, although still only a laboratory development, does offer an additional prospect for the future of lignite processing by hydrogenation.

Demonstration-Plant Operations

At the Bureau of Mines Coal-Hydrogenation Plant in Louisiana, Mo., the high-pressure hydrogenation of Velva, N. Dak., lignite was investigated on a semiplant-scale unit. In an extended run from October to December 1953, 1,665 tons of raw lignite was processed in the liquid phase, yielding 120,000 gallons of vapor-phase charge stock and 30,000 gallons of heavy oils. Subsequently 90,000 gallons of the charge stock was converted in the single-step vapor-phase unit into 89,000 gallons of 83 (Research) octane motor gasoline.

Liquid-Phase Hydrogenation

Description of Coal

Velva lignite is found in the Coteau bed in the extreme southeastern corner of Ward County, N. Dak. The bed is 10 to 18 feet thick and comprises an area, indicated to be some 250 square miles, underlying parts of 8 or 9 townships (5). The coal processed was mined about 10 miles southwest of Velva, N. Dak., and was obtained through the cooperation of Truax Traer Coal Co., Chicago, Ill.

Analyses of the coal are given in table 55. Several objectionable characteristics already discussed under Laboratory Investigation were recognized as inherent in the Velva lignite. However, despite these characteristics, the abundance and availability at low cost justified investigation of semiplant-scale processing of the lignite.

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TABLE 54. - Amounts and characterization of products obtained from hydrogenated lignites in fluidized bed

Run No.	Name	Press., p.s.i.g.	Temp., °C.	Yield, percent M.A.F.					H_2 consumed M.A.F. percent	Product oil properties								Residue properties						
				Organic solids	Oil	H_2O	CO_2	Gas		Asphalt, percent	Atomic H/C	H	Ultimate analysis, percent C	N	S	O	Atomic H/C	Ultimate analysis, percent H	C	N	S	O	Ash
224	Velva	1,000	600	23.2	29.5	17.0	11.2	23.6	4.38	53.6	0.98	7.07	86.68	1.02	0.08	5.15	0.40	2.47	73.32	0.61	0.24	1.82	21.54
236	do.	500	600	29.7	25.6	19.3	11.9	22.1	4.76	58.8	.97	7.01	86.70	1.04	.05	5.20	.42	2.58	73.02	.65	.18	6.39	17.18
226	do.	250	600	38.8	18.7	19.9	11.0	17.9	3.90	36.9	1.00	7.24	87.00	0.78	.06	4.92	.43	2.86	79.31	.75	.15	2.78	14.15
260	do.	1/0	600	61.1	5.7	11.0	15.2	7.5	-	-	-	-	-	-	-	-	.36	2.41	81.19	1.22	.20	5.45	9.53
228	do.	1,000	500	40.6	22.4	19.0	10.8	14.5	4.00	63.4	1.05	7.44	84.95	1.02	.06	6.53	.61	3.93	76.86	1.10	.19	4.48	13.44
229	do.	500	500	47.8	14.1	18.5	11.8	15.2	3.72	52.9	1.08	7.69	85.81	0.94	.09	5.47	.58	3.73	77.24	1.07	.19	6.01	11.76
227	do.	250	500	55.2	8.5	16.5	12.1	12.8	2.85	37.3	1.21	8.49	84.13	.49	.10	6.79	.56	3.67	79.28	1.18	.26	5.23	10.38
246	Beulah	1,000	600	20.8	31.0	18.1	11.5	23.8	5.33	64.5	1.00	7.18	85.91	.92	.24	5.75	.45	2.40	64.56	.58	.93	.00	31.53
252	do.	500	600	31.3	23.0	18.5	13.0	20.0	4.40	58.1	1.01	7.16	85.46	.92	.32	6.14	.45	2.72	72.20	.63	.76	.33	23.36
250	do.	250	600	39.	14.8	18.4	14.0	18.8	3.84	41.8	1.13	8.03	85.19	.92	.25	5.61	.41	2.55	75.30	.70	.78	.89	19.78
259	do.	1/0	600	59.4	5.8	10.4	14.4	9.9	-	-	-	-	-	-	-	-	.36	2.35	77.94	1.10	.84	3.70	14.07
251	do.	1,000	500	34.6	24.8	17.2	13.5	13.5	4.06	69.8	1.04	7.29	84.47	.90	.30	7.04	.59	3.50	71.13	.89	.44	2.66	21.38
248	do.	500	500	44.7	17.3	17.3	13.0	13.1	3.39	48.8	1.11	7.70	83.38	.93	.29	7.70	.57	3.58	74.88	1.05	.37	3.15	16.97
249	do.	250	500	50.4	13.7	16.5	13.4	10.4	2.70	48.8	1.13	7.79	82.43	.82	.36	8.60	.56	3.54	76.17	1.02	.46	3.13	15.68
245	Texas	1,000	600	14.6	41.4	15.2	9.2	25.6	4.09	34.4	1.14	8.14	85.52	1.17	.51	4.65	.42	1.84	52.25	.65	.00	.00	45.26
240	do.	500	600	24.2	34.0	15.7	9.9	22.2	3.33	32.7	1.19	8.48	85.27	1.07	.55	4.63	.43	2.27	63.46	.88	.50	.00	32.89
242	do.	250	600	37.7	23.3	15.5	10.2	18.3	-	11.5	-	-	-	-	-	-	.43	2.53	70.26	.98	1.10	.68	24.45
258	do.	1/0	600	59.1	12.1	13.3	12.5	4.1	-	-	-	-	-	-	-	-	.39	2.45	74.56	1.47	.92	3.44	17.16
238	do.	1,000	500	36.7	31.7	15.9	9.0	13.3	2.08	45.1	1.21	8.54	84.49	1.14	.52	5.31	.58	3.25	67.51	1.31	.57	3.77	23.59
239	do.	500	500	40.6	27.2	14.5	9.7	13.1	1.72	22.2	1.26	8.81	84.23	1.01	.54	5.41	.56	3.25	69.30	1.49	.51	2.93	22.52
241	do.	250	500	48.7	15.5	15.5	10.4	15.7	1.78	11.7	1.36	9.48	83.78	.80	.80	5.14	.56	3.36	72.52	1.56	.66	2.33	19.57
230	Arkansas	1,000	600	15.6	47.4	16.0	6.9	18.3	3.43	19.1	1.33	9.46	85.35	.77	.28	4.14	.51	1.16	27.06	.34	.08	1.14	70.22
231	do.	500	600	23.2	36.2	16.9	6.9	20.9	3.37	12.9	1.38	9.84	85.71	.64	.28	3.53	.45	1.35	35.79	.53	.13	1.15	61.05
234	do.	250	600	29.6	28.4	16.4	6.8	22.3	3.17	9.9	1.44	10.24	85.61	.56	.36	3.23	.47	1.61	41.15	.59	.18	1.12	55.35
244	do.	125	600	33.5	29.2	15.7	6.4	17.4	2.08	7.9	1.51	10.75	85.32	.38	.33	3.22	.43	1.56	43.95	.65	.20	1.87	51.77
254	do.	25	600	40.0	24.0	14.9	7.0	15.4	1.53	9.1	1.46	10.41	85.60	.24	.30	3.45	.44	1.77	47.83	.68	.40	1.75	47.57
257	do.	1/0	600	44.7	21.7	14.5	7.7	12.0	-	-	-	-	-	-	-	-	.41	1.69	48.95	.99	.40	3.12	44.85
237	do.	1,000	500	26.2	42.6	13.2	6.2	10.5	2.38	17.6	1.39	9.84	85.14	.70	.16	4.16	.61	1.87	36.77	.67	.12	2.78	57.79
232	do.	500	500	33.9	32.9	15.5	6.6	14.7	2.44	12.9	1.46	10.32	84.65	.57	.31	4.15	.59	2.08	42.63	.82	.25	2.72	51.50
233	do.	250	500	39.1	25.2	15.0	6.5	17.7	2.40	6.9	1.48	10.47	85.04	.52	.29	3.68	.58	2.16	44.99	.91	.31	3.49	48.14
243	do.	125	500	44.4	26.6	13.5	6.1	11.1	1.37	5.5	1.51	10.75	85.32	.38	.33	3.22	.60	2.34	47.07	.97	.43	4.09	45.10
253	do.	25	500	47.2	22.3	13.1	6.6	12.9	1.28	7.1	1.53	10.84	84.85	.26	.39	3.66	.57	2.29	48.02	.96	.42	4.51	43.80

1/ In zero-pressure runs, helium was used as the fluidizing gas.

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TABLE 55. - Coal analyses - Velva (N. Dak.) lignite

	As rec'd	M.a.f.		M.f.	M.a.f.
Proximate:			Ultimate:		
Moisture	35.9	-	Carbon	63.0	70.6
Vol. matter	28.3	49.5	Hydrogen	4.2	4.7
Fixed carbon	28.9	50.5	Nitrogen	1.1	1.2
Ash	6.9	-	Sulfur	.7	.7
			Oxygen	20.2	22.8
Petrographic:1/			Ash	10.8	-
Anthraxylon		61	C/H	15.0	15.0
Trans. attritus		27			
Opaque attritus		9	Alkalinity:		
Fusain		3	Grams H_2SO_4/Kg coal	70.5	70.5

1/ Storch, H. H., Hirst, L. L., Fisher, C. H., and Sprunk, G. C., Hydrogenation and Liquefaction of Coals, Part I: Bureau of Mines Tech. Paper 662, 1941.

Processing

The liquid-phase process was essentially that for high pressure hydrogenation as practiced in Germany and briefly described under Commercial Plant Operation but incorporated American-designed equipment and instrumentation throughout. Operating conditions and yields typical of the liquid-phase operations on Velva lignite are presented in table 56 and analyses of pertinent process and product streams in table 57.

The high moisture content of this coal taxed the capacity of the grinding and drying equipment, designed for processing 8 to 10 tons per hour of low-moisture bituminous coals and from the beginning determined the rate of coal input to the hydrogenation unit. It was not possible to supply enough prepared coal for acceptable converter operations and to dry the coal to less than 8 to 10 percent moisture. A maximum drying rate of some 2.5 to 3.5 tons of "dry" coal per hour was attained by maintaining the temperature of the inert gas to the ball mill at 650° F., some 200° hotter than was required for normal operation on bituminous coals. The high moisture in the prepared coal did not present serious difficulties. Some foaming occurred in paste making, which was eliminated by reducing the paste oil temperature to 190° F.

The catalysts used were copperas, $FeSO_4 \cdot 7H_2O$, and copperas plus ammonium molybdate, $(NH_4)_2MoO_4$. The copperas was added dry to the wet coal before grinding and drying, and the ammonium molybdate was added as a powder to the dried coal at the paste-mixing tank in the quantities shown in table 56.

The yields as shown were good with both catalysts. Conversion to light oils, although low in percentage of the total organic coal substance, was of the order of 58 to 60 percent based on the coal carbon. Liquefaction was consistent with the amount, as indicated by petrographic analyses of relatively inert substances of the coal. Gasification was not excessive, considering that over one-third of of the gas produced was CO_2, which eliminates coal oxygen without consumption of hydrogen.

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TABLE 56. - Operational and yield data - liquid-phase processing of Velva lignite

	Period I	Period II
Operational:		
Pressure, p.s.i.:		
Inlet	8,400	8,400
Outlet	7,600	7,800
Conversion temperature, °F. (average)	85.8	84.6
Coal, moisture-free, tons/day	58.9	50.8
Coal, moisture and ash free, do.	51.8	44.8
Coal, moisture and ash free, lb./cu.ft./hr.	24.0	20.7
Paste, do.	76.6	75.0
Paste, percent m.a.f. coal	31.7	27.6
Paste oil, percent < 620° F.	13.7	12.2
Total gas to converters, cu.ft./lb. m.a.f. coal	85.2	106.7
H_2, percent by volume	83.4	81.9
Makeup H_2, cu.ft./lb. m.a.f. coal	18.8	21.8
Yields, weight-percent on m.a.f. coal:		
Total gases	18.9	18.1
Hydrocarbon gases	11.9	11.1
Light oils, C_5 + to 620° F.	47.4	49.9
Benzene soluble heavy oils, > 620° F.	15.0	13.5
Asphalts	3.0	4.2
Coal liquefaction	94.8	94.8
Oil yields, bbl./ton m.a.f. coal:		
LP gases	0.6	0.5
Light oils	2.9	3.1
Heavy oils (benzene-soluble)	.8	.7
Total oils	4.3	4.3
Space time yields, lb./c.f.h.:		
Light oils	11.4	10.3
Heavy oils	3.6	2.9
Hydrogen consumption, lb./lb. m.a.f. coal:		
Total H_2	0.094	0.109
Reaction H_2	.058	.059

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TABLE 57. - Typical analyses of process streams and products - liquid-phase hydrogenation of Velva lignite

	Catalyzed m.f. coal	Paste oil	H.O.L.D.	L.O.B.	Middle oil	Naphtha	Gasoline
Ultimate - wt.-percent:							
Ash	12.2	6.4	16.9	Nil	-	-	-
Carbon	61.8	82.7	73.4	88.2	86.7	82.8	84.2
Hydrogen	4.3	7.5	6.1	8.4	9.4	9.8	13.1
Nitrogen	0.9	0.9	0.8	0.8	0.9	0.8	0.3
Sulfur	0.8	0.5	1.3	0.03	0.05	0.04	0.1
Oxygen	20.0	2.0	1.5	2.6	2.9	6.5	2.3
C/H	14.3	11.0	12.0	10.5	9.2	8.5	6.4
Insoluble materials - wt.-%:							
Benzene-insol.		8.5	22.6	Nil	-	-	-
Pet. ether-insol.		12.3	29.2	do.	-	-	-
Density:							
Sp. gr. $60/60^\circ$ F_δ		1.126	1.274	1.056			
API		-	-	-	10.8	16.4	48.5
Distillation - °F.:							
I.b.p.				570	313	209	122
10%				658	532	350	178
30%				685	565	412	217
50%				708	582	443	245
70%				742	596	473	273
90%				-	614	513	313
E.p.				-	643	565	355
Recovery, percent:							
Total				81.2	98.2	98.3	97.6
At 500°F.					5	84	-
At 620°F.		12.9	13.0	4	93	-	-
Chemical analyses, percent:							
Tar acids					21.7	39.2	3.5
Tar bases					5.0	4.6	1.5
Olefins					19.8	12.7	20.8
Aromatics					46.9	30.0	16.3

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Distribution in the hydrogenation products of the organic components of the lignite was as follows:

	Period I weight-percent	Period II weight-percent
Carbon:		
Gasification	16.0	15.1
Light oils[1]	57.1	61.2
Total oils[1]	77.4	78.3
Liquefied	93.4	93.4
Nitrogen: To NH_3	47.0	50.0
Sulfur: Organic S to H_2S	53.3	36.1
Oxygen:		
To CO and CO_2	22.0	22.1
To water	63.8	64.8
Total elimination	85.6	86.9

1/ Includes tar acids and bases in the liquor.

The percentage of conversion of coal carbon to light plus heavy oil equaled that attained previously in bituminous-coal operations.

Performance of Equipment

In general, processing equipment performed well on lignite. Improved operation was obtained from nearly all the injection pumps. Stellite inserts were used successfully, for the first time, as valve seats. Packing replacements were low - only six during the entire run. The largest maintenance item on the injection pumps was replacement of ball-type valves. More than normal failure for these valves seemed to occur during the run.

No difficulties were encountered in operating the paste preheater. For the first time, no scaling or deposition of solids occurred in any tubes of this radiant-type heater. Better heat transfer was evinced by lower tube temperatures for the same heat load as for previous runs. Whether this good performance was due to characteristics of the coal and paste oil, better firing, or the low solids content of the paste (38 to 42 percent) was not ascertained.

Inability of the coal-preparation unit to furnish enough coal steadily for proper operation of the converters caused considerable difficulty. Hot-spot reactions developed several times, necessitating quenching of excessive temperatures with cooling gas and pasting oil. The sudden coolings caused small leaks in flange joints, which required lowering of the system pressure for sealing. As the run progressed, it became evident that solids had deposited in the converters, and the run was stopped to make corrective changes. As the coal-preparation plant was unable to handle the requisite quantities of lignite for proper operation of the converters, plans were made to reduce their internal diameter to suit the capacity of the coal-preparation plant.

Removal of solids from the heavy-oil letdown (H.O.L.D.) was more difficult than in previous operations. Apparently, either because of the character of the heavy oil and solids or because of a high rate of feed to the centrifuge, the efficiency of solids removal by centrifugation decreased appreciably. Low solids removal by centrifugation forced removal of the major portion of the solids made

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by flash distillation - an operation accompanied by exorbitant oil losses, resulting in depletion of heavy oils by 30,000 gallons more than was made in hydrogenation. The total oil loss incurred in removing solids was equivalent to 1.4 barrels per ton of m.a.f. coal processed.

The pitch made in flash distillation was very viscous and sticky, and three times during the operations the bottom head had to be removed to permit the lower section of the flash drum to be cleaned. Improved flash nozzles performed well with little or no trouble from the coking experienced in previous runs.

Vapor-Phase Hydrogenation

Conversion of the Velva lignite liquid-phase light oils into a good-grade motor gasoline did not offer particular problems. These light oils responded to vapor-phase hydrogenation similarly to light oils from hydrogenation of bituminous coals, both in yields and quality of gasolines made.

Approximately 90,000 gallons of lignite light oils were processed during 10 days' operation in April 1953. Typical onstream operating conditions are presented in table 58 and yields and analyses of pertinent streams in tables 59 and 60, respectively.

The catalyst used was a pelleted fixed-bed-type German catalyst (2) designed for one-step conversion and refining of coal-hydrogenation oils.

TABLE 58. - Typical operating conditions - vapor-phase hydrogenation

Pressure, p.s.i.:	
Stall inlet	10,000
Stall outlet	9,350
Converter temp., °F.:	
Average	892
Maximum	930
Feed injection:	
Gallons per hour	945
Lb./cu.ft./hr., total oil	72.1
Lb./cu.ft./hr. >375 °F.	64.9
Recycle, vol.-percent	51.8
Gas flows, cu.ft./lb. feed consumed:	
Feed injection gas	94.9
Cooling gas	13.6
Total to stall	108.5
H_2, percent	-
Makeup H_2 gas	10.6
Catalyst:	
Type	K-536
Volume, cu.ft.	100

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TABLE 59. - Typical yields - vapor-phase hydrogenation

Yields based on total oil feed, wt.-percent:	
Gasification:	
Carbon monoxide, carbon dioxide	-0.8
Net hydrocarbon gases	5.3
Gasoline	38.4
Recycle bottoms	55.1
Total oils	93.5
Conversion of >375° oils, wt.-percent:	
Gasoline	33.5
Hydrocarbon gases	6.6
Total	40.1
Yields based on converted material, wt.-percent:	
Gasoline	83.5
Hydrocarbon gases	16.5
Yields based on feed consumed:	
Gasoline, wt.-percent	85.5
vol.-percent	102.6
Hydrocarbon gases, wt.-percent	11.8
Space time yields, lb./cu.ft./hr.:	
Total gasoline	28.6
Gasoline from >375° F. feed	21.5
Reaction hydrogen based on feed consumed, wt.-percent	4.0

TABLE 60. - Typical analyses of feed and product streams - vapor-phase hydrogenation

	Virgin feed	Feed blend	Recycle bottoms	Finished gasoline
Gravity-°A.P.I.	22.8	23.3	23.3	54.2
Distillation, °F.:				
I.b.p.	124	156	408	92
10	202	382	432	136
30	406	440	448	186
50	496	472	472	227
70	552	512	506	270
90	628	580	574	324
E.P.	666	630	642	392
Percent recovered	-	97.5	98.0	98.0
Percent at 375° F.	25.0	9.0	0	-
Chemical analyses, vol.-percent:				
Tar acids	24.8	12.6	2.4	0.8
Tar bases	2.8	1.4	2.4	.8
Olefins	20.8	11.5	4.5	3.3
Aromatics	29.9	49.1	61.8	27.2
Ultimate analyses:				
Carbon	85.4	86.9	88.4	86.3
Hydrogen	10.6	10.9	10.8	13.4
Nitrogen	.4	.3	.1	.02
Sulfur	.4	.3	.3	.03
Oxygen (by diff.)	3.2	1.6	.4	.3
Octane number (clear):				
Motor method				
Research				83.0

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Bibliography

1. CLARK, E. L., PELIPETZ, M. G., STORCH, H. H., WELLER, S., AND SCHREIBER, S. Hydrogenation of Coal in a Fluidized Bed. Ind. Eng. Chem., vol. 42, 1950, pp. 861-865.

2. CLARKE, E. A., CHAFFEE, C. C., AND HIRST, L. L. Hydrogenation of Petroleum and Lignite-Tar Distillate. Bureau of Mines Rept. of Investigations 4676. 1950, 27 pp.

3. FISHER, C. H., SPRUNK, G. C., EISNER, A., O'DONNELL, H. J., CLARK, L.. AND STORCH, H. H. Hydrogenation and Liquefaction of Coal; II. Effect of Petrographic Composition and Rank of Coal. Bureau of Mines Tech. Paper 642, 1942, 162 pp.

4. HIRST, L. L., MARKOVITS, J. A., SKINNER, L. C., DOUGHERTY, R. W., AND DONATH, E. E. Estimated Plant and Operating Costs for Producing Gasoline by Coal Hydrogenation. Bureau of Mines Rept. of Investigations 4564, 1949, 83 pp.

5. LEONARD, A. G., BABCOCK, E. J., AND DOVE, L. P. The Lignite Deposits of North Dakota. North Dakota Geol. Survey Bull. 4, 1925, p. 40.

6. MINISTRY OF FUEL AND POWER. Report on the Petroleum and Synthetic Oil Industry of Germany. His Majesty's Stationery Office, London, 1947.

7. WELLER, S., PELIPETZ, M. G., FRIEDMAN, S., AND STORCH, H. H. Coal Hydrogen Catalysts; Batch Autoclave Tests. Ind. Eng. Chem., vol. 42, 1950, pp. 330-334.

8. WILEY, J. L., AND ANDERSON, H. C. Bibliography of Pressure Hydrogenation, II. Patents. Bureau of Mines Bull. 485, 1951, 286 pp.

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5. OTHER CHEMICAL PROCESSING

Although no definite conclusion has been reached as to the fundamental molecular structure of coal, it may be considered to be a complex organic colloid, physically heterogeneous. The individual coal molecule consists basically of hexagonal carbon rings making up different polycylic structures, with naphthenic and other ring structures occurring to a lesser extent (17).1/ Generally, the older the coal, the more the plant compounds have been converted to the larger polycylic molecules. Although the large-molecular portions of the coal molecule are of potentially great interest, actually at present the lower molecular weight degradation products are of the greatest commercial value.

Lower molecular weight compounds with existing or potential chemical markets may be obtained from coal in various ways. Methods by which coal generally is treated may be classified under the following general headings:

1. Pyrolysis(carbonization).
2. Hydrogenation.
3. Gasification.
4. Extraction.
5. Partial oxidation.

Pyrolysis, hydrogenation, and gasification have been discussed in detail in other sections of this report. The additional chemical processing methods listed also may have possibilities for economic development, though probably on a smaller scale.

Extraction consists of dissolving or extracting a portion or all of the coal substance by suitable solvents and then recovering the desired fractions from the solution. The extraction process is an important research tool for obtaining information concerning the fundamental nature of coal. Commercial applications also exist, particularly for the low-rank coals, and the process of selective extraction may become more important in the future.

By controlled partial oxidation degradation is lessened, and complex substances such as humic acids are obtained in addition to the usual combustion products of carbon dioxide and water. The distribution and complexity of the degradation products depends upon the severity of oxidation and the nature of the original material.

Another potential source of chemicals is the coal ash; included are both inherent and extraneous ash. Certain elements, such as uranium or germanium (9), may have been concentrated in special cases in the coal ash to an extent not generally found elsewhere, as discussed in more detail in section 3, part 1.

Products for other than fuel use that are now produced from United States lignites on a commercial basis include: Montan wax; "active" carbon, a treated char; water softening or treating agents; wood stains; and oil-well drilling-mud additives. Several small industries are operating profitably producing these materials. These commercial applications are discussed in the following sub-sections.

1/ Underlined numbers in parentheses refer to citations in the bibliography at the end of this section.

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Activated Carbon

Vegetable-type carbons activated by treatment with various atmospheres such as steam, air, or carbon dioxide are used widely for decolorizing solutions. The field of utilization extends also to diverse applications, such as water treatment, recovery of solvents, gas absorption, recovery of gold, and extraction of iodine. Declorizing-type carbons can be prepared from lignite or almost any substance containing carbon. For example, flax waste, moss, coconut hulls, wood, molasses, and other materials have been used for this purpose.

Treated lignite used as activated carbon belongs to class 3 of the vegetable declorizing carbons, as classified by Mantell (11) on the basis of manufacturing methods. Class 3 decolorizing chars are made by thermal treatment of such carbonaceous materials as lignite, sawdust, woods, and waste pulp liquors. Activation treatments vary widely with the mechanical strength, porosity, and other factors dependent upon raw material. Owing to the complexity of the factors determining the activity of carbons in various applications, comparison on the basis of laboratory tests, or even dissimilar commercial uses, often is difficult and may have little value. Two carbons may contain the same amount of active carbon; one may be an efficient decolorizer, the other an efficient gas adsorbent. Both, however, may be nearly worthless when the applications are interchanged (12).

The Atlas Powder Co. Darco plant, which has been operating at Marshall, Tex., since 1922, is the only commercial plant in the United States known to be manufacturing activated carbon from lignite. In 1952 the plant was reported to have a capacity of about 2 million pounds of carbon per month (1). Alloy-steel retorts externally heated by natural gas are used. No attempt is made to recover byproducts. The strip-mined lignite contains about 31 percent moisture as charged.

Manufacture of Darco activated carbons, as reported by Evans (5), consists of four steps, as follows:

1. Carbonizing the crushed minus-7/8-inch lignite in retorts.
2. Acid-water washing the burned product.
3. Grinding and air-classifying the washed material.
4. Packaging sized material for shipment.

According to the patent of R. W. Mumford (12, 13), lignite is first reduced in size to 10- to 16-mesh material, and the water-soluble constituents are removed. Before burning or carbonization, a paste is made by adding 1 to 15 percent milk of starch or gelatinous tricalcium phosphate. From 5 to 50 percent of 80- to 100-mesh dolomite also is mixed thoroughly with the paste. Progressive heating takes place in rotary kilns. Formation of water vapor in the paste gives considerable porosity to the material. The dolomite spacing agent prevents overheating until decomposed. Heating continues until 800° to 900° C. is reached; the treated material is then discharged into a water bath. The ash is reduced by acid treatment, and the carbonized material is activated by air and steam at controlled temperatures.

Generally two grades of active carbon are produced. Most of the material is marketed as finely divided Darco, 70 to 90 percent minus-300-mesh. Darco may be used in decolorizing and purifying liquids and solutions, including sugars, syrups, oils, solvents, chemicals, and pharmaceuticals (5). Hydrodarco, a more granular product, is used in water filtering and purification plants to remove objectional odors, taste, and colors.

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Darco grades S-51 and G-60 contain 74 to 76 and 93 to 96 percent carbon, respectively. The corresponding ash contents are 23 to 26 and 3 to 6 percent, 0.5 percent or less of the material being soluble in hydrochloric acid. The chars are very slightly acid; pH of the water extract is 4.5 to 6.0. This is considered important for the adsorption of amphoteric substances (12). Another important characteristic of the Darco chars is their relatively high density either in loose or solid pack, as compared to other commercial activated carbons of similar grade.

Recent data on production of Darco activated carbons from lignite are presented in figure 25 (1). In 1952, Darco production represented 40 percent of total United States output of activated carbons, excluding gas carbons.

The University of North Dakota School of Mines became interested in activated carbon from North Dakota lignite in 1933, owing, in part, to water-purification problems accentuated by drought conditions. Laboratory investigations and pilot-plant work were carried out in cooperation with North Dakota and Federal relief organizations. Results of this work are summarized by Bloomquist (2).

Amick and Lavine prepared an active carbon from carbonized Velva lignite by activation with superheated steam (2). Material treated at the higher temperature (950° C.) compared favorably with the corresponding Darco product. The North Dakota product compared with Darco had approximately twice the adsorptive capacity for benzoic acid (42.5 to 21.3 percent, respectively) and nearly the same percentage of iodine adsorption (46.4 to 49.1 percent). Without acid washing, however, the activated chars were relatively poor molasses decolorizers. Acid washing increased the decolorizing at the expense of benzoic acid and iodine-adsorption properties. Cooley prepared activated carbon on a pilot-plant scale, using steam activation in a rabble-type furnace. Selected chars compared favorably for water-purification use with commercial products with respect to phenol values and threshold odor numbers; however, difficulty was encountered in obtaining a uniform product. The furnace operation was relatively inefficient and apparently unsuitable for commercial application without extensive modification.

Before activated carbon can be produced commercially from North Dakota lignite, further experimental work would be required. In addition to known procedures, consideration should be given to the application of fluidized techniques for carbonization and steam activation as a possible approach to the problem.

A market exists for activated carbon in the North Central States, which could be met by activated carbon produced from North Dakota lignite. A portion of this market would be as decolorizing and treating agents in the sugar-beet-processing industry. In northwestern Minnesota refineries are in operation at East Grand Forks and Moorhead, with another large plant under construction at Crookston.

Additional activated carbon could be used in water purification. The problem of obtaining potable drinking water is quite difficult in the North Central States, especially during drought years, and considerable activated carbon is used for this purpose. Usually each town with a municipal water supply employs activated carbon to some extent. In Grand Forks, N. Dak., a minimum of approximately 40 pounds of activated carbon is used per million gallons of water treated.

Stain-Type Dyes and Related Products

A water-soluble brown coloring material that finds a market as a wood stain or stain base can be extracted commercially from naturally weathered or slacked lignite. According to Dove (4), the coloring material is a complex mixture similar to the ulmic or humic materials occurring in unaltered coal substance. Two commercial plants

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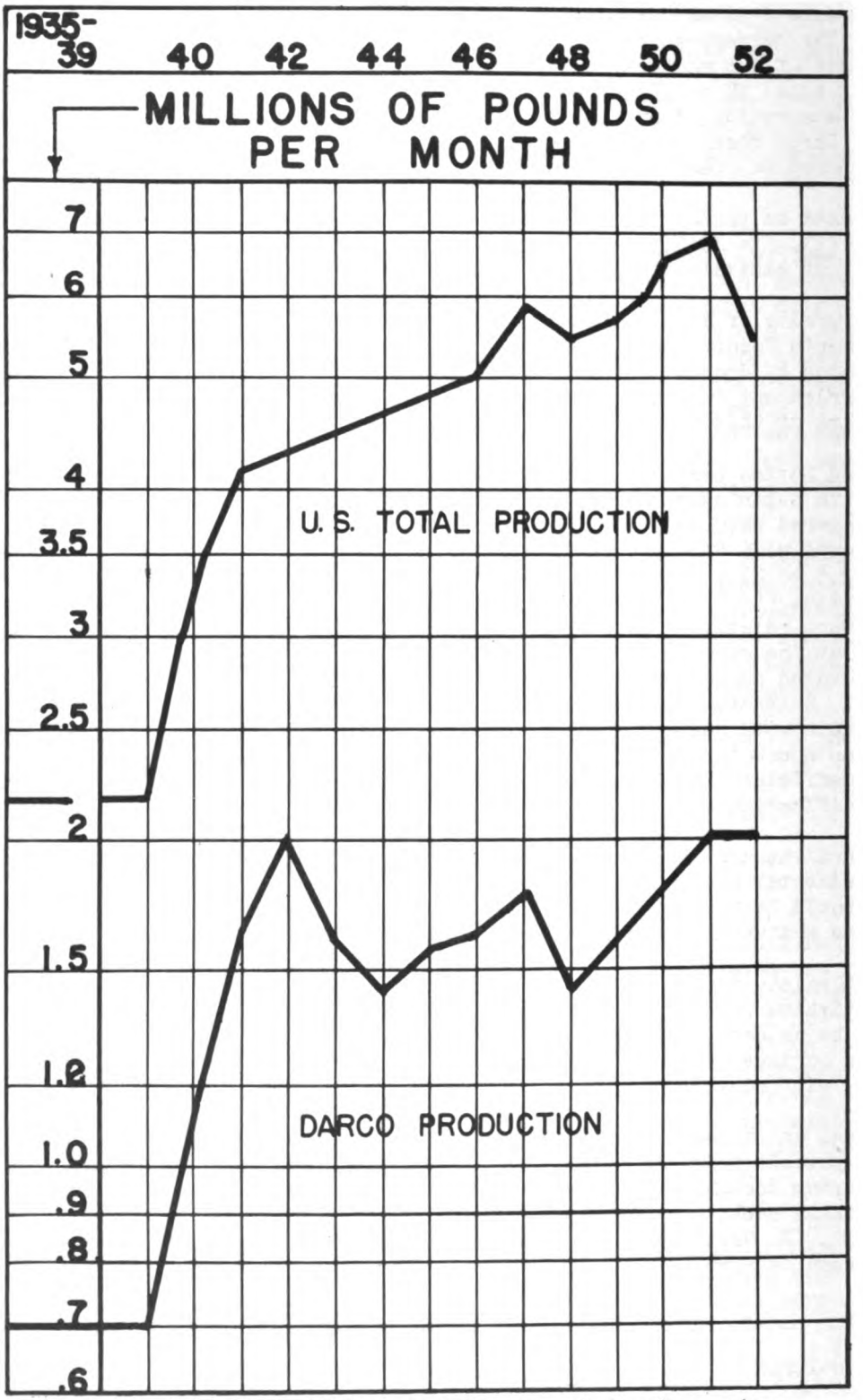

Figure 25. - Production trends for activated carbon exclusive of gas carbons.
(Source: Darco Department, Atlas Powder Co.)

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have been in operation in the United States for recovery of the water-soluble stain. One plant near Bowman, N. Dak., has produced various grades of stain material under the general trade name of Dakalite; the other produced a similar dye from Arkansas lignites.

The Arkansas production was begun at El Dorado, where a small plant was operated for some 3 years after 1938 by the American Dyewood Co. Both flake and granules of Vandyke brown were produced. In 1941, some 700 tons of lignite was used. The material was processed at El Dorado or at an associated plant in New Jersey. The New Jersey plant was moved in 1943 to Malvern, Ark., where both stain and montan wax were produced by an undisclosed process. During the war years, consumption of lignite at this plant may have exceeded 1,000 tons per year. The operation was abandoned in 1947 owing to the return of imported montan wax to the market (14).

The North Dakota operation has a longer history, having been started in 1923 by L. P. Dove, formerly North Dakota State geologist. The coloring material Dakalite is extracted from minerallike weathered or oxidized lignite called leonardite. When treated with an alkaline solution, the oxidized lignite or leonardite forms a water-soluble reversible colloid. Production of Dakalite consists of extracting leonardite in hot alkaline solution, decanting, and evaporating the dye-containing solution to near dryness. The moist Dakalite is dried further in a rotary-type kiln, ground, and packaged. Various grades of oil-and water-soluble Dakalite have been marketed (6).

The original plant was constructed near Minot in the fall of 1925 and moved to Burlington a year later. For about 15 years, processing was carried out at Bowman, N. Dak. Recently, processing facilities at Bowman were taken over by the National Aluminate Corp. and are now used to obtain lignite products for water treatment. According to information released by the National Aluminate Corp., the processing at Bowman consists only of partial drying, without chemical treatment. The material is later treated in various ways and mixed with large percentages of other chemicals before being used for water treatment. Details of processing, as well as production figures, are not available. Production is stated by the corporation to be, "exceedingly small as compared with that of lignite production for other purposes."

An oil-well drilling-mud additive is manufactured from oxidized lignite by the Baroid Division of the National Lead Co. at Haynes, N. Dak. Small amounts of the additive in alkaline solution are included to improve the settling characteristics of the entrained solids (10). No details of the processing operation are available at present.

Montan Wax

Montan wax is a natural wax, which may be extracted from some coal substances, usually brown coal or lignite, by suitable organic solvents. Composition of the wax varies, depending upon raw material and type of solvent used. Waxy constituents, such as monohydric alcoholic esters and high-molecular-weight acids predominate, with resinous and asphaltic material occurring in lesser amounts. Chemical compounds that have been identified are various esters, acids, alcohols, ketones, hydrocarbons, and resins (14). Physically, commercial crude montan wax has a relatively high melting point (185° F.) and is hard and brittle. The refined grades exhibit compatibility with paraffin waxes. A few important applications of montan wax are carbon paper, polishes, phonograph records, rubber, electrical insulation, inks, greases, protective coatings, and adhesives. Lignites vary widely in their wax content, and only a few American lignites have enough waxmaking constituents to make wax recovery economically feasible under present conditions (14).

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Before World War II montan wax was imported. The volume of imports in 1930 was 12.5 million pounds. Imports ranged from 5 to 9 million pounds annually during the next 9 years, with about 7 million pounds worth $700,000 entering the country in 1939. Little or no wax was imported during the war years (14).

Domestic commercial production of montan wax has been from California and Arkansas lignites, that from Arkansas coming from the American Dyewood Co. plant at Malvern. The American Lignite Products Co. has produced montan wax from California lignite since 1948 at Ione, Calif. (16). Lignite deposits of the American Products Co. in the vicinity of Ione, Calif., occur in lenses of relatively small diameter, ranging from 500 to 3,000 feet and varying in thickness. The strip-mined lignite is first crushed to approximately 1/2-inch particles and then pulverized in a hammer mill swept by hot products of combustion. Approximately 80 percent of the pulverized material passes a 200-mesh sieve. The finely ground lignite is fed to an extractor and extracted batchwise by petroleum solvents, which dissolve predominantly wax esters, resinous bodies, and asphaltic substances. Discharge from the extractor is separated into extract and extracted lignite by a series of filters. Solvent is removed from the extract in steam-heated stills, from which the liquid wax is drained and transferred to pans for cooling and solidification. The recovered wax is crushed and bagged for shipment. Solvent retained by the filter cake is reclaimed by steam distillation to keep solvent losses at a minimum. A simplified process diagram is shown in figure 26.

Approximately 280 pounds of crude montan wax is obtained from 1 ton of lignite of 25-percent moisture content, and substantial production is now underway (3). At present the company produces only crude, hard, dark-brown montan wax available in two grades and marketed under the brand name Alpco. Type 16 wax sells for 25.0 to 26.5 cents per pound, whereas the price of type 235, a partly refined wax, ranges from 28.5 to 31.0 cents per pound.2/

Information on properties of lignite mined for wax extraction and of extracted residue calculated to the MAF basis is given in table 61.3/

TABLE 61. - Properties of lignite mined for wax extraction

	Lignite, as mined	Lignite, as processed	Extracted lignite
Moisture.....percent	36.8	11.7	10.2
Volatile matter.percent, MAF	69.5	68.7	65.3
Fixed carbon.....do.	30.5	31.3	34.7

Reduction of volatile matter content as a result of wax-extraction should be noted. General properties of American montan wax are presented in table 62.

Spent lignite from wax-recovery operations is used as an additive to control the viscosity of drilling mud in the tanning industry and in the production of fertilizer as a filler. It is claimed that spent residue has fertilizing properties, acts as mulch, improves soil porosity, restores organic matter, and contributes humic acid to the soil.

2/ From a letter written by F. J. Deangelis, General Manager, American Lignite Co., Aug. 5, 1953.
3/ See footnote 2.

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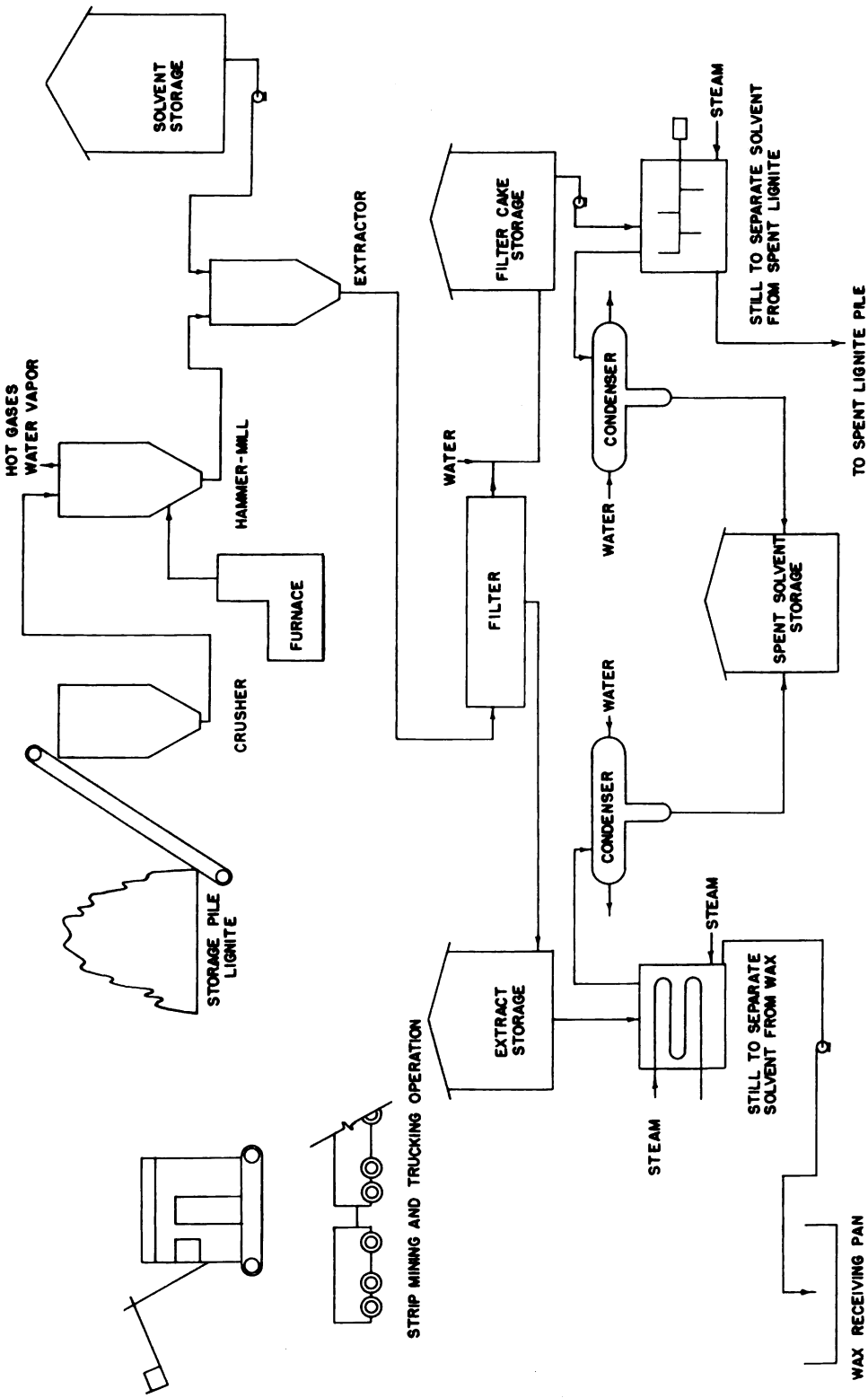

Figure 26. - Process diagram: Extraction of Montan wax from lignite, American Lignite Products Co., Ione, Calif.

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TABLE 62. - General properties of American montan wax[1/]

	Alpco 16	Alpco 235
Type		
Melting point, ASTM, D-127-49, °C.	83 - 85	82 - 84
Acid value	50 - 55	45 - 50
Saponification value	118-124	107-112
Color	Brownish-black	Brownish-black
Resin (cold ethyl ether), percent	21 - 24	19 - 21
Asphaltic constituents (paraffin method), do.	3.3-3.8	2.9-3.3
Ash, do.	0.2-0.5	0.2-0.4
Specific gravity	1.02-1.03	1.02-1.04
Fracture	Conchoidal	Conchoidal
Insoluble material (hot benzol)	Trace	-
Ultimate analysis, percent:		
Ash	0.2	
Carbon	79.4	
Hydrogen	12.2	
Nitrogen	0.0	
Sulfur	0.3	
Oxygen	7.9	

1/ From a letter written by F. J. Deangelis, general manager, American Lignite Co., Aug. 5, 1953.

Extraction yields from various American lignites and some subbituminous coals, are compared in table 63 using benzene-ethyl alcohol solution as determined in laboratory experiments by Selvig (14). Extraction yields with benzene-alcohol solutions were from one and one-half to two times those obtained with benzene alone, owing in part to solution of more resinous and asphaltic substances. Selected samples having the highest wax yields are reported for each type.

Yields from the American Lignite Products mine, Ione, Amador County, Calif., were the highest. Yields from this lignite were 6 times greater than yields from North Dakota samples. Extracts from subbituminous coals tested were comparable to those from the Dakota lignites, whereas those from Texas lignites were slightly higher.

Recovery of Elements in Ash

Many coals, including lignite, have certain elements present that may be relatively concentrated compared to the average percentage existing in the earth's crust. Chemical properties of these elements are quite dissimilar, with chemically diverse elements such as beryllium, strontium, boron, scandium, zirconium, vanadium, cobalt, copper, gallium, germanium, arsenic, silver, and uranium having been reported. More common elements, such as calcium, aluminum, iron, phosphorus, and sulfur, make up the bulk of coal mineral matter (9).

At present, two elements, germanium and uranium, are of particular interest. Uranium deposits in lignite occur to the greatest extent in an area including southwestern North Dakota, northwestern South Dakota, and southeastern Montana. The concentration of uranium in natural lignite is variable, but in the area mentioned some beds contain slightly over 0.01 percent (8). Burning the lignite would result in concentration of the uranium about tenfold. Such a residue may be considered for commercial uranium recovery. The possibility of using lignites with high uranium content in existing power plants and recovering the ash has been suggested (8).

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TABLE 63.—Extraction yields of selected lignites and subbituminous coals (13)

Laboratory Number	State	County	Mine	Yield of extract, percent 1/ 2/		
				As tested	Dry basis	Dry, ash-free basis
			Lignite			
45738	Arkansas	Dallas	American Dyewood	12.0	14.0	16.5
46084	do.	Hot Spring	Outcrop	14.0	16.7	20.4
46085	do.	do.	do.	16.4	18.1	22.7
46602	California	Amador	American Lignite Products	21.2	23.4	27.9
45571	do.	do.	Buena Vista	11.2	12.5	15.3
46000	Montana	Powder River	Black Diamond	2.9	3.4	3.7
45797	N. Dak.	Ward	Miller	2.7	3.3	3.7
45804	do.	Williams	Blue Vein	3.4	4.0	4.5
45808	do.	do.	Standard	2.6	3.3	3.8
46115	Texas	Harrison	Darco Number 3	4.2	5.4	6.1
46112	do.	Milam	Sandow	4.8	5.7	6.4
45867	Washington	King	Prospect opening	4.3	4.8	5.7
45994	do.	Lewis	Drill hole	3.3	4.0	4.7
			Subbituminous C			
45872	Wyoming	Converse	Badger	3.6	4.0	4.4
45856	do.	Weston	Cummings	3.0	3.3	3.6
			Subbituminous B			
46083	Colorado	El Paso	Franceville	3.6	4.1	4.7
46041	Wyoming	Fremont	George	3.5	4.1	4.6

1/ Samples as tested were air dried, minus-20-mesh in size.
2/ Extraction with 80 percent benzene - 20 percent ethyl alcohol solution.

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Germanium is essential in manufacturing transistors and is in short supply. The only commercial source of germanium in the United States is in byproduct recovery from the production of electrolytic zinc. The current price of germanium is about $350 per pound, and some 2.5 million pounds of zinc ore is processed for each pound of byproduct germanium recovered. The average germanium content of coal is about 0.001 percent, making the germanium in each ton of coal worth about $7. Interest in the recovery of germanium from coal ash is increasing with market demand. Future needs have been estimated at 20,000 to 80,000 pounds yearly.

Enrichment of germanium in coal is generally believed to be the highest in woody coal occurring at the top and bottom of the normal coal seam and in sediments. High-ash coals usually have lower total germanium contents than otherwise comparable low-ash coals because the germanium is ordinarily present in the inherent rather than the extraneous ash. The extent and nature of the mineralization of the surrounding rocks, as well as the type of coal-forming plants, may also have important bearing on the germanium content. Some 26 localities have been sampled recently in Montana, North Dakota, and Wyoming (15). Three of the samples - 2 from Montana and 1 from North Dakota - contained enough germanium (about 0.21 to 0.23 pound of germanium oxide per ton of coal) to be listed as germanium rich. It should be noted, however, that in the reconnaissance sampling only the blocks most likely to contain concentrations of germanium were tested; for example, the top and bottom of the seam, and woodylike coal.

Controlled Oxidation

Lignite and other coals may be oxidized at low temperatures, with partial degradation to relatively high molecular weight products, such as aliphatic acids, water-soluble polycarboxylic aromatic acids, and complex so-called humic acids, in addition to the usual carbon dioxide and water of high-temperature oxidation. The nature of the degradation products depends upon the oxidation method and the material oxidized.

A pilot-plant process for controlled oxidization of higher rank coals was developed at the Coal Research Laboratory of the Carnegie Institute of Technology (7). Essentially, the process consisted of oxidizing a coal, alkali, and water mixture at from 200° to 300° C. under 600 to 1,200 p.s.i. pressure. Ash and insoluble carbonaceous material were removed by filtration. The solution was acidified with mineral acid and extracted with methyl-ethyl ketone. The solvent was distilled from the extract until a syrup consisting of 50 to 70 percent aromatic acids was obtained. After further drying in a vacuum rotary drier, the acids were pulverized in a ball mill. The total yield of acid averaged approximately 50 percent of the coal weight and of finished acid about 32 percent.

Data indicate that the lower the coal rank the greater the reactivity and the lower the yield of carboxylic acids with cyclic groupings (7). Potential uses for these coal-oxidation acids are as plasticizers; in the production of glyptal resins, as lubricants, as metal cleaners, as dispersing agents, and as substitutes for other organic acids. The potential demand for the coal acids, chiefly as replacement for phthalic acid, has been estimated at some 150 million pounds per year, at prices not over 15 cents per pounds.

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Miscellaneous Applications

Several miscellaneous applications of lignite for other than combustion uses, either in processed or natural forms, have been suggested. Of interest would be the manufacture of various carbon electrodes and brushes, ion-exchange material, and calcium or silicon carbides.

According to Lowry (11, p. 359), sulfonation of natural coal substance produces a high-capacity base-exchange material. The apparently greater reactivity of lignite might be of value in developing an exchange material. Low cost would aid competition with synthetic resins for large applications.

At present, electrode and brush carbon is made primarily from graphite, anthracite, or pitch. Low ash content is advantageous for preparation of electrode carbon. In preparing carbons for electrothermal processing - production of phosphorus and of calcium and silicon carbide - requirement as to ash content is less severe. Although lignite has a relatively low carbon content, satisfactory carbons for electrothermal uses could presumably be produced if local demand, based on cheap power, should develop.

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Bibliography

1. ATLAS POWDER CO. Information provided by Darco Department, Marshall, Tex.

2. BLOOMQUIST, C. R. The Production of Activated Carbon From Lignite. North Dakota Works Prog. Admin., Rept. of Project 1791, August 1937.

3. CHEMICAL INDUSTRIES. American Montan. Vol. 64, March 1949, pp. 379-380.

4. DOVE, L. P. Dakalite. Univ. of North Dakota Bull. 9, 1926, pp. 33-35.

5. EVANS, G. L. Activated Carbon From Texas Lignite. Univ. of Texas Bureau of Econ. Geol., Min. Res. Circ. 30, June 1944, 2 pp.

6. FISCHER, S. A. The Manufacture of Dakalite. North Dakota Engineer, Univ. of North Dakota, vol. 3, No. 4, May 1927, pp. 6, 10.

7. FRANKE, N. W., KIEBLER, M. W., RUOF, C. H., SAVICH, T. R., AND HOWARD, H. C. Water-Soluble Polycarboxylic Acids by Oxidation of Coal. Ind. Eng. Chem., vol. 44, No. 11, 1952, pp. 2784-2792.

8. GEOLOGICAL SURVEY. Selected Papers on Uranium Deposits in the United States. Circ. 220, 1952, 35 pp.

9. GIBSON, F. H., AND SELVIG, W. A. Rare and Uncommon Chemical Elements in Coal. Bureau of Mines Tech. Paper 669, 1944, 23 pp.

10. LAWTON, H. C., LOOMIS, A. G., AND AMBROSE, H. A. Drilling Wells and Well Drilling Fluid. United States Patent 1,999,766, Apr. 30, 1935.

11. LOWRY, H. H., (editor). Chemistry of Coal Utilization. John Wiley & Sons, New York, N. Y., 1945, vol. 1, 920 pp.

12. MANTELL, C. L. Industrial Carbon. D. Van Nostrand Co., Inc., New York, N. Y., 2d ed. 1946, 472 pp.

13. MUMFORD, R. W. U. S. Patent 1,286,187, 1918.

14. SELVIG, W. A., ODE, W. H., PARKS, B. C., AND O'DONNELL, H. J. American Lignite: Geological Occurrence, Petrographic Composition, and Extractable Waxes. Bureau of Mines Bull. 482, 1950, 63 pp.

15. STADNICHENKO, T., MURATA, K. J., ZUBOVIC, P., AND HUFSCHMIDT, E. L. Concentration of Germanium in the Ash of American Coals, A Progress Report. Geol. Survey Circ. 272, 1953, 34 pp.

16. TIDEWAYS, PORT OF STOCKTON. American Lignite Co., Only U. S. Makers of Montan Wax. Vol. 2, No. 9, July 1953, pp. 2, 3, 12.

17. WILSON, P. J., AND WELLS, J. H. Coal, Coke and Coal Chemicals. McGraw-Hill Book Co., Inc., New York, N. Y., 1st ed., 1950, 509 pp.

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